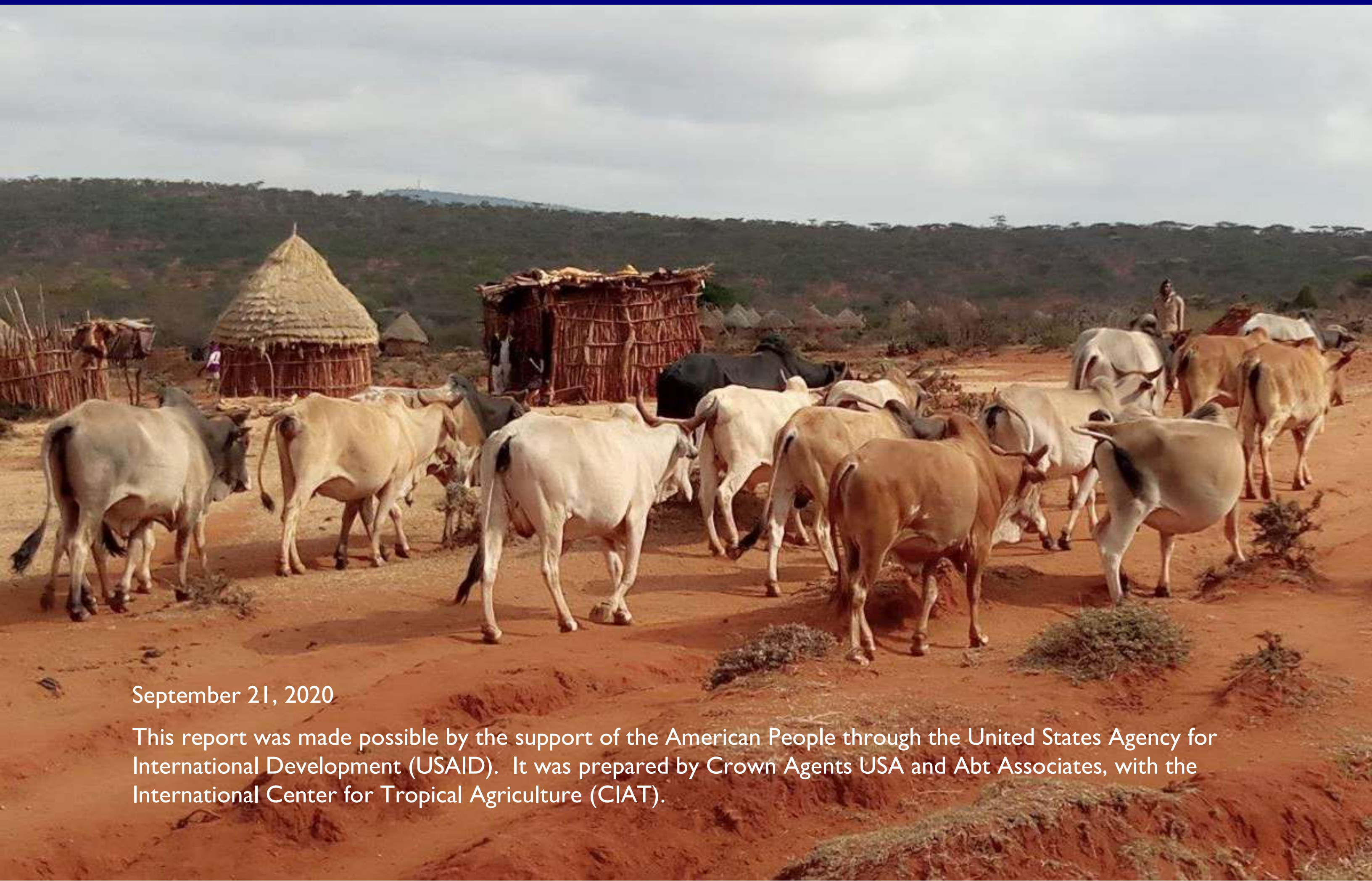
COST-BENEFIT ANALYSIS OF IMPROVED LIVESTOCK MANAGEMENT PRACTICES IN THE OROMIA LOWLANDS OF ETHIOPIA

CLIMATE ECONOMIC ANALYSIS FOR DEVELOPMENT, INVESTMENT, AND RESILIENCE (CEADIR)

Contract No.: AID-OAA-I-12-00038, Task Order AID-OAA-TO-14-00007



September 21, 2020

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACRONYMS AND ABBREVIATIONS

BAU	Business-as-usual
Br	Birr (Ethiopian currency)
C	Celsius
CCAFS	CGIAR Research Program on Climate Change, Agriculture and Food Security
CBA	Cost-benefit analysis
CEADIR	Climate Economic Analysis for Development, Investment, and Resilience (USAID-funded activity)
CGIAR	Consultative Group on International Agricultural Research
CH4	Methane
CIAT	International Center for Tropical Agriculture
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
E3	Bureau for Economic Growth, Education, and Environment (USAID)
EP	Economic Policy Office (E3)
GCC	Global Climate Change Office (E3)
GDP	Gross domestic product
GHG	Greenhouse gas
GoE	Government of Ethiopia
GWP	Global warming potential
ha	Hectares
ILRI	International Livestock Research Institute
IPCC	Intergovernmental Panel on Climate Change
km	Kilometers
LAND	Land Administration to Nurture Development (USAID-funded activity)
m	Meters
mm	Millimeters
N_2O	Nitrous oxide
NGO	Nongovernmental organization
NPV	Net present value
PRIME	Pastoralist Areas Resilience Improvement and Market Expansion (USAID-funded activity)
SNNPR	Southern Nations, Nationalities, and Peoples Region
T	Metric tons
tCO_2e	Metric tons of carbon dioxide equivalent
SAPARM	Satellite Technology to Improve Pastoral Decision Making
TLU	Tropical livestock unit
USAID	United States Agency for International Development

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EXECUTIVE SUMMARY

This study analyzed the costs and benefits of improved management practices for cattle, small ruminants, camels, and poultry. It focused on agropastoralists that have settled farm locations and also graze livestock extensively. It addressed three types of improved livestock management practices:

1. **Deferred-rotation grazing.** A simple form of intensive pasture management with a longer resting period between uses for livestock grazing, typically two years. This method excludes livestock from specific grazing areas, often through enclosures, so that the vegetation has enough time to regenerate naturally. Natural regeneration increases the vegetative cover and diversity and reduces water runoff and soil erosion. The resting period increases soil tilth and fertility, and carbon sequestration and storage (Mekuria *et al*. 2007; Adem *et al*. 2016).
2. **Active restoration of degraded rangeland.** Planting or seeding desired herbaceous species and removal of woody plants to restore productivity for grazing.
3. **Fodder cultivation (supplementation).** Planting crops with products or byproducts that have high nutritional value for livestock to supplement grazing or reduce use of purchased feeds. Some fodder crops also produce food for household consumption or sale (e.g., maize, wheat, barley, and teff). The addition of high-quality fodder to the diet of ruminants can also reduce greenhouse gas (GHG) emissions per unit of animal product produced.

This study was conducted in the Yabello District (Woreda) in the Borena Zone of Oromia Region.

CEADIR conducted individual surveys and group interviews of livestock farmers in areas where improved management practices for livestock had been used for at least two years. The surveyors focused on farmers with five years of agropastoral experience before and after adoption of the improved pasture management practices. In selecting sites, CEADIR considered the number of households that applied the improved livestock management practices, duration of use of the improved practices, accessibility from Yabello town, ability of the field team to speak the local language or find translators, and team safety.

In late 2018, CEADIR gathered data on the costs, revenues, and other benefits of the prior traditional and improved livestock production practices. The sampling frame only included agropastoralist households who raised cattle, sheep and goats, but the survey collected information on all types of livestock and crops that they produced. The survey reached 86 households who had participated in improved livestock management (28 for deferred-rotation grazing, 29 for active restoration of degraded lands, and 29 for fodder cultivation). After completing the surveys, the field team held focus group discussions with the three pastoralist associations in Yabello.

The data covered normal rainfall, moderate drought years, and one severe drought after improved practices were implemented in 2016. The team defined an *instance* as a combination of a livestock management practice, household, year, and animal type. Households who were able to provide information on drought years reported that 66 percent of the instances involved moderate droughts.

CEADIR conducted a cost-benefit analysis (CBA) of each improved management practice to compare it to the business-as-usual (BAU) practices that those households used before they implemented the new practice. The time period covered in the survey questions included normal and drought conditions and, as a result, the cost and revenue data collected reflected the average outcomes of normal rainfall and droughts. The CBA addressed severe drought risks by modeling the worst herd losses based on the historical frequency of severe droughts.

The CBA included a financial analysis and an economic analysis. The *financial analysis* reflected the costs and benefits to the agropastoralists. The *economic analysis* estimated the effects on the national economy. The time horizon for the financial analysis was based on the time required to implement the three types of improved practices and their expected operating life and effectiveness. This varied from 15 to 20 years, depending on the specific improved practice.

Rangelands in the study area were shared by village members, and multiple households worked together to improve the communal grazing areas. The CBA used different assumptions of the average amount of land that households devoted to each improved practice: 1.74 hectares (ha) for fodder cultivation, 0.5 ha for active restoration of degraded rangeland, and 2.5 ha for deferred-rotation grazing.

The economic analysis also included the carbon sequestration and storage from adoption of the improved practices and the methane emissions from changes in ruminant livestock populations. CEADIR based the GHG impacts on published studies of areas with similar conditions. The time horizon of the economic analysis was 50 years. The economic analysis valued the carbon emissions reduction at $8 per metric tons of carbon dioxide equivalent (tCO_2e) in the base case and $15/$tCO_2e$ and $25/$tCO_2e$ in sensitivity analyses.[1,2]

The financial analysis found that all three improved management practices had positive net present values (NPVs) for the livestock producers at a 12 percent real discount rate. The NPV per participating household was highest for active restoration of degraded rangeland ($3,130), followed by fodder cultivation ($2,235) and deferred-rotation grazing ($1,740). At the 12 percent discount rate, the incremental financial NPV per household for the improved practices was positive for active restoration of degraded rangeland ($2,914) and fodder cultivation ($2,299) over the life of the practice. Deferred-rotation grazing had a negative incremental financial NPV per household (-$1,423) at the 12 percent discount rate, but a positive economic NPV at a 3 percent discount rate over 50 years ($2,069). At the 3 percent discount rate over 50 years, the incremental financial NPVs were higher for degraded rangeland restoration ($14,767) and fodder cultivation ($8,316).

The sensitivity analysis found that positive incremental NPVs could still occur after accounting for the risk of serious droughts. At a12 percent discount rate over 50 years, the economic NPV with serious droughts was $1,515 for fodder cultivation and $1,152 for active restoration of degraded rangelands. However, in both cases, there would be many one or two-year periods with negative net revenues.

All three of the improved livestock management practices had long breakeven periods: four years for fodder cultivation, six years for active restoration of degraded rangeland, and 12 years for deferred-rotation grazing. As a result, livestock farmers would need long-term loans to make these investments feasible. Even if loans are available, livestock farmers might not be interested in making these investments without a subsidy because their time horizons are likely to be shorter than the breakeven periods.

Rangeland restoration increases the vegetative cover that sequesters carbon. Soil carbon would increase with active restoration of degraded rangeland and deferred rotation grazing. Soil carbon would not increase with fodder cropping, which is often done on land that already had a grass cover and may undergo tillage. Secondary data indicated that grasses in tropical drylands of Africa sequestered an average of 1.72 tCO_2e per hectare per year (Conant *et al.* 2017). CEADIR assumed that the soil carbon sequestration would continue at a constant rate for 20 years and then stop.

[1] The carbon dioxide equivalent ($CO2_e$) is calculated by multiplying by the mass of carbon by 44/12.

[2] All monetary values in the CBA are in 2018 U.S. dollars converted at the exchange rate of Br 28.4 per dollar.

All three of the improved management practices make it feasible for farmers to increase livestock production, typically from larger herd sizes. Methane emissions will increase as the ruminant livestock population grows. Methane has a higher global warming potential per ton than carbon dioxide. Over decades, the negative value of cumulative methane emissions from larger ruminant livestock populations will exceed the positive value of the carbon sequestration of some improved livestock management practices.

With a 12 percent discount rate and a social cost of carbon of $8/t$CO_2$e, the GHG impacts over 50 years would have an NPV of $113 for deferred-rotation grazing, negative $95 for active restoration, and negative $57 for fodder cropping. Under these assumptions, the total economic NPVs were not significantly different from the financial NPVs to households over the 15- to 20-year operating life of the improved practices.

Improved livestock management practices may also have additional economic and environmental benefits, such as greater food security in drought years and reduced dust concentrations in the air. Although these benefits could be substantial, CEADIR did not quantify or value them due to time, budget, and data limitations.

CEADIR also considered the potential for increasing poultry production separately from the improved production practices for ruminant livestock. The surveyed households raised poultry on a low-input basis. Many households viewed chickens as semi-wild animals that mostly fended for themselves, rather than as managed livestock, but some did feed poultry. Poultry can provide important food products for households and income-generating opportunities for women.

GHG emissions per unit of protein are much lower for poultry meat and eggs than ruminant meat. If diets can be modified by shifting ruminant meat consumption to poultry protein, total GHG emissions from livestock could be reduced if ruminant populations are allowed to decrease. However, this might not happen if farmers retain ruminant livestock as a store of wealth.

1. INTRODUCTION

The U.S. Agency for International Development (USAID) Global Climate Change Office asked the Climate Economic Analysis, Development, Investment, and Resilience (CEADIR) Activity to conduct a cost-benefit analysis (CBA) of improved pasture management practices for cattle, small ruminants, camels, and poultry in the Oromia Lowlands of Southern Ethiopia. This study focused on agropastoralists with settled farm locations who also graze livestock extensively.

1.1 LIVESTOCK PRODUCTION IN ETHIOPIA

Livestock production contributed about 17 percent of the gross domestic product (GDP) of Ethiopia and 39 percent of the agricultural GDP in 2013 (Shapiro *et al*. 2017). However, livestock management is often inefficient in Ethiopia, with low and unreliable returns that leave many livestock-producing households in poverty (Rettberg *et al*. 2017).

Most of the cattle production was in mixed agropastoralist systems. Sheep production was fairly evenly distributed between highland mixed and lowland grassland systems. Goats and camels were mainly raised at elevations below 1,500 meters (m) in lowland pastoral and agropastoral systems, (Shapiro *et al*. 2017). Approximately 60 percent of Ethiopia's lowlands were arid or semi-arid.

Shapiro *et al*. (2017) estimated that 60 million ha of rangelands were grazed in Ethiopia in 2015 and that livestock consumed 120 percent of the annual forage production in average weather years. The forage deficits were higher in drought years and have been exacerbated by increasing livestock populations. As a result, livestock productivity per animal has declined.

Rettberg *et al*. (2017) reported that most of the rangeland in Ethiopia was already degraded and had sparse vegetation. Herders in arid and semi-arid areas have traditionally moved livestock to deal with droughts. As the ability to move livestock to different areas decreases, other approaches are needed to reduce animal mortality rates and support production during droughts. The Government of Ethiopia has encouraged voluntary settlement of pastoralists and communal rangelands are increasingly enclosed and privatized.

The future productivity of livestock and crop production in the Ethiopia lowlands is highly vulnerable to land degradation from overgrazing as well as climate variability and change. *Overgrazing* occurs when livestock populations exceed the carrying capacity of rangelands or degrades land so that it is only suitable for episodic grazing. Overgrazing reduces the density and diversity of the vegetative cover of pasture lands and can lead to soil erosion, land degradation, and decreased water infiltration rates.

The main climate risk is drought, which reduces crop and livestock productivity and increases livestock mortality rates and pest and disease problems (Traore *et al.* 2013). Higher temperatures may exacerbate drought impacts. Viste *et al*. (2013) reported that the frequency of droughts has increased in southern Ethiopia during the spring, with seasonal precipitation decreasing by 2.6 mm from 1971 to 2010. They also found that total annual precipitation has decreased in southern Ethiopia, but not throughout the country.

More recently, Suryabhagavan (2017) concluded that total annual precipitation in Ethiopia had not decreased, but was becoming more variable across large portions of the country, leading to more droughts and floods. Teshome and Zhang (2019) reported modeling projections that extreme droughts will increase in Ethiopia due to global warming.

Climate change could increase the relative importance of pastoralism versus sedentary crop and livestock farming in arid and semi-arid areas of Ethiopia. Traditional cattle varieties grazed in Ethiopia may be better adapted to water and high temperature stresses than imported varieties used in sedentary livestock production (Rettberg *et al*. 2017).

Since many droughts are local, grazing animals can be moved to less affected areas. The USAID-funded, Satellite Technology to Improve Pastoral Decision Making (SAPARM) Activity developed an automated, mapping process to estimate the amount of green vegetation in traditional grazing grounds. SAPARM updated the maps every 10 days and shared them with local communities. After a one-year pilot, 78 percent of the pastoralists in these areas used the SAPARM maps and there was a 47 percent reduction in livestock mortality.[3]

The largest source of global greenhouse gas (GHG) emissions from livestock is methane from the anaerobic digestion process of ruminants. Ruminants break down cellulose from vegetation in their first stomach (*rumen*) to obtain energy and nutrients, producing methane as a byproduct. Large ruminants (such as cattle) produce more methane per animal than small ruminants (goats and sheep). However, the total methane production per kilogram of animal weight is similar for large and small ruminants. In other words, small ruminants generate as much methane as large ruminants when the total biomass of the herds is the same.

The decomposition of animal waste also releases nitrous oxide, another GHG (Herrero *et al*. 2013; Wood 2010). Animal waste can fertilize rangeland plants, which may increase carbon sequestration, but this positive effect is often small relative to the negative effects of overgrazing on carbon storage. Livestock manure is often stored under wet conditions in lagoons at large farms or intensive feedlots, generating methane through anaerobic decomposition. At the global level, livestock waste is a significant source of methane. However, this is not the case for extensive livestock grazing on arid or semi-arid lands, where manure dries quickly on the ground, producing negligible methane emissions.

GHGs differ in their ability to absorb energy (*radiative efficiency*) and persistence in the atmosphere (*lifetime*). Their relative contributions to global warming are estimated in carbon dioxide or carbon equivalents and vary with the time horizon. By definition, carbon dioxide has a global warming potential (GWP) of one over a 100-year period. Methane (CH_4) has a higher radiative efficiency, but shorter lifetime, than carbon dioxide. The global warming potential of methane is 28-36 times that of carbon dioxide (CO_2) over 100 years and 84-87 times as much over 20 years. Nitrous oxide (N_2O) has 265-298 times the global warming potential of CO_2 over a 100-year period and can remain in the atmosphere for even longer (U.S. Environmental Protection Agency 2017).

Improved production practices can reduce or mitigate the negative impacts of grazing livestock on rangelands. Improved practices can decrease the GHG emissions per unit of animal products by increasing yields per animal (Kashangaki and Ericksen 2018). Improved practices can also speed up the production cycle and reduce livestock mortality and morbidity rates (Herrero *et al.* 2013; Vétérinaires sans Frontières 2018). However, if ruminant populations increase, total GHG emissions may increase even if the emissions per animal fall.

1.2 PURPOSE AND APPROACH OF THIS STUDY

Ericksen and Crane (2018) defined *improved livestock management* as the deliberate control and movement of livestock for feeding and watering, reducing disease risks, and reducing vegetation and land damage by livestock. Examples of improved practices include conserving or restoring the quality of

[3] https://www.usaid.gov/div/portfolio/pci-pastoralists

grazing lands and increasing fodder cultivation. Improved livestock management can increase the yield of livestock products for income generation and household consumption, reducing GHG emissions per unit of production. However, improved practices are often more costly for farmers and pastoralists in terms of initial capital investments or annual production costs (including labor). It can also take considerable time for farmers and pastoralists to learn, adopt, implement, and show positive results from improved practices. Consequently, it is important to understand the short-, medium-, and long-term effects of individual improved practices on the net incomes of livestock producers to gauge their willingness to adopt the practices.

Cost-benefit analyses assess the financial and economic desirability of investments and may be ex ante or ex post. *Ex ante analyses* are prepared in the design or prefinancing stages of investments and are important for efficient allocation of government, development assistance organization, or private sector resources. They can improve the design and implementation of support activities and help convince livestock producers understand the value of adopting improved practices. *Ex-post analyses* are useful in monitoring and evaluation and can indicate whether the original assumptions were valid and identify the effects of changing conditions and risks. This information can guide mid-course corrections during implementation and inform decisions on expansion and replication efforts.

Kashangaki and Ericksen (2018) conducted a CBA on Napier grass fodder cultivation as a low emission development strategy for dairy cattle in Kenya. They found that this production system was beneficial, but farmers needed extension services to adopt it. However, their study sites in Kenya had enough annual precipitation to grow Napier grass without irrigation. Most areas in the Oromia lowlands do not receive rain to grow Napier grass without irrigation. The Kenyan dairy farmers in the Kashangaki and Ericksen study had relatively good access to urban markets. Most livestock farmers in the Oromia lowlands raise cattle and other ruminants for meat, rather than milk. It is too expensive for livestock farmers in the Oromia lowlands to transport milk to urban and peri-urban markets.

Ericksen and Crane (2018) identified nine potential low emission development interventions for livestock production in Kenya and Ethiopia in three categories: 1) improving feed quality and availability, 2) manure management, and 3) animal husbandry. The feed quality interventions were improved forage species; supplementation with feed blocks; producing silage from maize; and improving pasture on rangelands. Manure management interventions included the use of biodigesters and manure storage. The animal husbandry interventions were reducing the chronic disease burden from intestinal parasites and ticks; slaughtering meat animals at a younger age; and the use of artificial insemination to improve animal genetics.[4]

CEADIR's CBA for the Oromia lowlands assessed the financial and economic viability of pasture management changes to improve the condition of lands under extensive grazing. Because of the importance of meat production in arid- and semi-arid areas, CEADIR selected three of the improved livestock management practices analyzed by Ericksen and Crane (2018):

1. **Deferred-rotation grazing.** This simple method of pasture management prevents or reverses rangeland deterioration by allowing a longer resting period, typically two years, between cycles of livestock grazing. Farmers exclude livestock from the area, often through enclosures, until natural regeneration has sufficiently restored the vegetation. Natural regeneration increases the vegetative cover and plant diversity. It can increase soil fertility and tilth, reduce water runoff and soil erosion,

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[4] Other studies have used CBA to assess the viability of ecosystem-based adaptation to reduce flood risks (Daigneault, Brown, and Gawith 2016), improved soil management for crop production in Western Kenya (Ng'ang'a, Girvetz, *et al.* 2017), and climate-smart agriculture in the coastal savannah of Ghana (Ng'ang'a, Ansah *et al.* 2017).

and increase carbon storage (Mekuria *et al*. 2007; Adem *et al*. 2016). This approach has been used in Tanzania, Kenya, and South Africa (Mekuria *et al.* 2018).[5]

2. Active restoration of degraded rangeland. This pasture management method restores the productivity of degraded grazing lands by planting seeds or plants of desired herbaceous species and removing woody vegetation. This method is costly, but may be the only viable approach for severely degraded lands that cannot recover with just a resting period.

3. Fodder cultivation. This method reduces grazing pressures on rangeland. Livestock farmers grow high-quality fodder species or purchase animal feeds to supplement or eliminate grazing. Some fodder crops also produce food for household consumption or sale (e.g., maize, wheat, barley, or teff). Adding high-quality fodder crops to the diet of ruminants can also improve their digestive efficiency, reducing the GHG emissions per unit of animal product.

These three types of improved production practices are mutually exclusive. In other words, only one type can be implemented on a particular site. This CBA focused on agropastoralists that combined livestock herding with crop cultivation. It did not address pastoralists that do not manage the land used by their livestock.

CEADIR gathered data on the costs and benefits of the improved production practices for cattle, sheep, goats, and camels through a survey of livestock farmers and pastoralists and subsequent focus group discussions with each of the three pastoralist associations that represented the surveyed households. The team used data from the household surveys and focus groups for a CBA of the improved production practices.

A *financial analysis* reflected the perspective of the farmers, including the benefits of subsidies and costs of taxes. The CBA reflected the average amount of land that a household devoted to the improved practices: 2.5 ha for deferred-rotation grazing, 0.5 ha for active restoration of degraded rangeland, and 1.74 ha for fodder cultivation. The expected duration of the benefits from the three alternative practices varied from 15 to 21 years.

CEADIR had planned to consider the potential for more intensive poultry production to increase household incomes and protein consumption at lower financial and environmental costs than production of other types of livestock. The GHG emissions per unit of protein are much lower for eggs and poultry meat than for ruminant meat (aan den Toorn *et al*. 2017). Shifting consumption of ruminant meat to poultry products could be a low emission development strategy, but it can be difficult to change food preferences in developing countries. Furthermore, the desired GHG emission reductions will not occur if farmers continue to hold ruminant livestock as a store of wealth. In the study area, poultry production was predominantly carried out by women. Public and private sector efforts to improve poultry production and profitability can be important in increasing the incomes of rural women.

Women in many of the surveyed households were involved in poultry, but with a very low level of capital investment and management. Some respondents considered their chickens to be more like wild animals than livestock. Typically, chickens were generally left to forage on their own, but were sometimes provided with feed. Women collected the eggs. Time and budget constraints precluded CEADIR from conducting a full financial and economic analysis of more intensive poultry production.

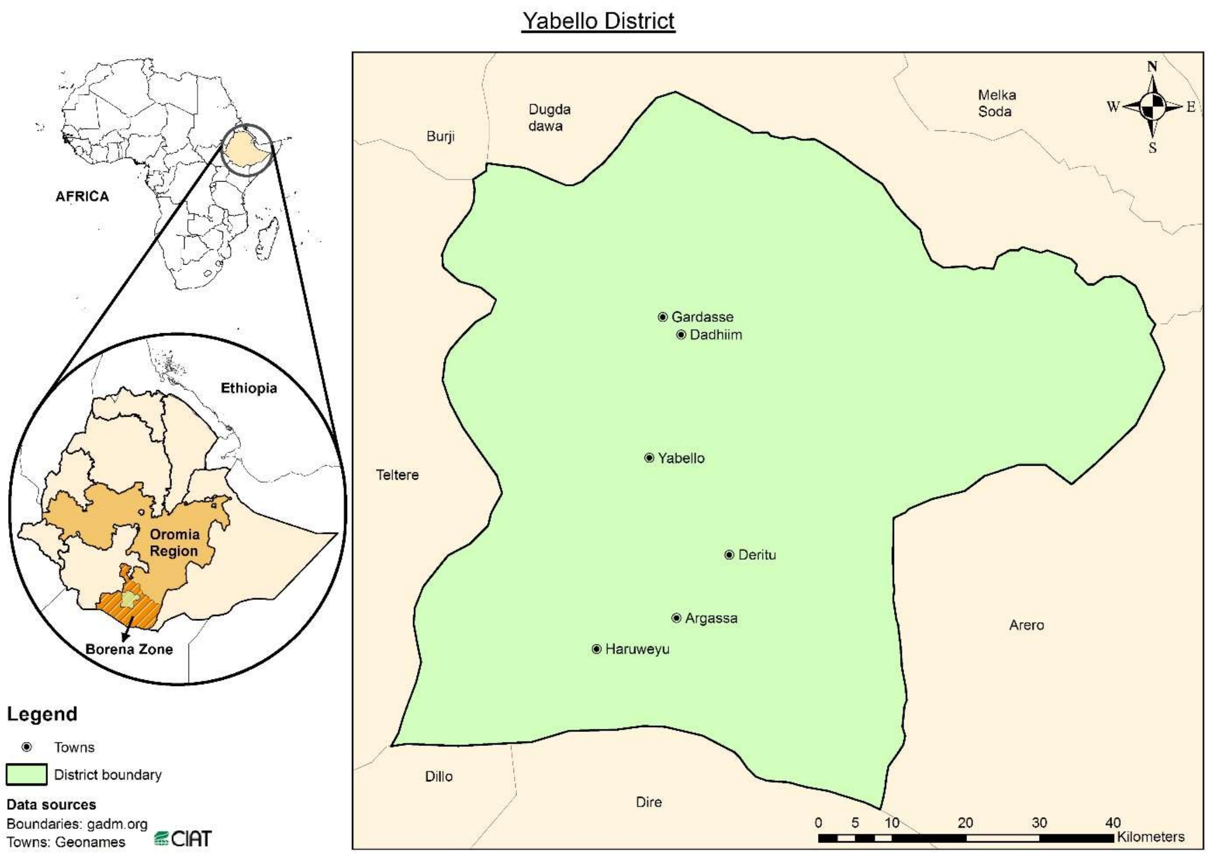
[5] *Soil tilth* refers to the formation and stability of aggregated soil particles and the moisture content, aeration, water infiltration, and drainage capacity of the soil.

2. STUDY METHODS

2.1 DESCRIPTION OF THE STUDY AREA

This study was conducted in Yabello District (Woreda) in the Borena Zone of Oromia Region (FIGURE 1).[6] Yabello District is located between 4°24' and 5°14' North, and 37°48' and 38°46' East. The capital, Yabello, is approximately 570 kilometers (km) south of Addis Ababa.

FIGURE 1. The Study Area



Borena Zone has a land area of approximately 95,000 square km (Tilahun *et al*. 2017). It had a population density of about 21 people/km^2 in 2007 (the most recent national census), far below the national average of 112/km^2 (Worldometers 2019). It is semi-arid, with large spatial and temporal variability in rainfall (Hussen *et al*. 2013). The mean annual rainfall in Borena Zone ranges from 238 to 896 millimeters (Dandesa *et al*. 2017). The rainfall is typically bimodal; long rains occur between March and May and short rains between October and November (Hussen *et al*. 2013). High rainfall variability within a year affects crop production and grazing land productivity. Even in average rainfall years, seasonal droughts are often long enough to reduce crop and livestock productivity substantially and sometimes lead to premature livestock deaths. The mean monthly temperature for the Borena region

[6] Ethiopia's administrative divisions include regional states and chartered cities, zones, woreda (districts), and kebele (wards).

of Ethiopia varies from 19°C to 26°C (Dandesa *et al.* 2017). The altitude of Yabello District ranges from 1,450 to 2,200 m (Robinson-Pant 2018).

Semi-nomadic pastoralism has been the primary livelihood in the study area, but fewer than 15 percent of households obtained all of their income from livestock production (Ng'ang'a, Giller *et al.* 2016). The grasslands in the Afar Zone, Somali Region, and Borena Zone had an estimated livestock population of 15 million cattle, 12 million sheep, 20 million goats, and 4.5 million camels in 2010 (Central Statistical Authority 2012). In Borena Zone alone, the estimated livestock population included 1.05 million cattle, 0.6 million sheep, 0.9 milion goats and 51,000 camels (Central Statistical Agency 2017). Livestock serves multiple uses in these areas, including a store of wealth.

Crop production only became common in the Borena Zone in the past 30 years. Migrants from the highlands introduced crop production, initially near urban areas. The total cultivated area was about 16,000 km^2 per year in 2008-2010 (most recent data available). Crop farming took place during the long rains from mid-February to mid-May. Most farmers cultivated less than 2 ha of crops, mainly teff, maize, wheat, sorghum, barley, and green beans (Mengistu and Amanu 2016).

Ethiopia has experienced contentious land policy debates that have involved many stakeholders, including the donor community. The central government continues to hold all land ownership rights (Crewett *et al*. 2008). Farmers only have *usufruct* (use) rights to land. As a result, farmers cannot sell land or use it as collateral for a loan and are uncertain about their ability to obtain long-term financial benefits from any land improvements. However, the Government of Ethiopia (GoE) has established a land certification program in four highland regions, including Oromia. This program has a relatively low cost to users, compared to land registration programs in some other African countries (Deininger *et al.* 2011). The GoE's stated reasoning for only granting limited land use rights is to protect low-income farmers from selling their land and losing their livelihoods. However, this policy has discouraged private investments that could reverse land degradation (Hagos and Holden 2006).

In recent years, centralization of land tenure and administration have increased in pastoral and agropastoral areas of Oromia Regional State. Historically, customary rules governed the use of rangeland resources, but customary authority has been undermined as the Oromia Regional State devolved authority over land ownership and use to local governments. In addition, some pastoral lands have been reserved for parks and protected areas or allocated to agricultural plantations (Stickler and Huntington 2005). These changes together with land encroachment, rural population growth, voluntary settlement of pastoralists, and climate change have increased pressures on the remaining pastoral land resources. USAID helped the GoE recognize customary pastoral land uses by supporting demarcation, certification, and registration under the Land Administration to Nurture Development (LAND) Activity in the Afar and Oromia Regions from 2013 to 2018. The LAND Activity helped customary institutions gain the authority to allocate land use rights for crop production (McPeak *et al.* 2014).

CEADIR selected locations within the study area where improved production practices for livestock had been used for at least two years so that data could be collected on production costs and revenues before and after adoption of the improved practices. Table 1 lists the characteristics of the pilot tests, including the type of improved practice, participating pastoralist associations, starting year, and the land area. All three of the pilot tests involved cattle, sheep, goats, and camels, but not poultry. Annex A contains additional information on the pilot tests.

TABLE 1. Characteristics of the Pilot Tests

Type of Improved Practice	Participating Pastoralist Association	Starting Year for the Pilot Test	Land Area (Hectares)[b]
Deferred-rotation grazing	Dadim	2014	1,500
Active restoration of degraded land	Harweyu	2015	1,000
Fodder cultivation	Dharito	2014	1,131

[a] Years 2014 and 2015 in the Gregorian calendar are 2007 and 2008 in the Ethiopian calendar.

[b]Estimated with Sentinel-2 satellite images at a 10 m resolution.

The Gayo Pastoral Development Initiative, a local NGO, funded the deferred-rotation grazing pilot test. There was no information on the number of farmers that participated in the field tests. However, all of the members of the Dadim and Harweyu Pastoralist Associations at the time of the pilot test participated. The Harweyu Association included over 100 villages. Only members of the Dharito Pastoralist Association had access to the communal grazing lands. Dharito Pastoralist Association started crop production about 20 years ago after the amount and quality of pasture land had decreased due to droughts that resulted in large losses of livestock. Each household in the association had access to valley land for maize, teff, and wheat production. However, they did not generally cultivate fodder crops before the Gayo Pastoral Development Initiative pilot test.

In selecting specific study sites, CEADIR considered the number of households that applied the improved practices, duration of use, accessibility from Yabello town, ability of the field team to speak the local language or find translators, and safety. Before conducting the household surveys, CEADIR met with multiple representatives of the Yabello judicial system (2), Yabello Legal Aid Office (3), Haramaya University College (3), Addis Ababa University (1), Ethiopian Ministry of Agriculture (4), Pathfinder International Ethiopia (2), and farmers (5). This meeting enabled CEADIR to identify pastoralist associations in Yabello District that had been involved in pilot tests of improved livestock production practices.

2.2 DATA COLLECTION

CEADIR gathered data on the traditional and improved livestock management practices through a survey of farming and pastoralist households followed by focus group discussions with the three pastoralist associations. The team developed a written questionnaire on livestock production systems and management improvements. The surveyincluded questions on the study sites; crop and livestock farming by members; capital and operating, maintenance, and replacement costs and revenues from business-as-usual (BAU) and improved livestock production practices; and market prices for inputs and outputs.

CEADIR hired eight enumerators and a local field management officer for the household surveys. It trained the enumerators for three days on good practices for administering a survey in three languages (English, Amharic, and Oromiffa) and entering responses on an Android tablet with Open Data Kit software (https://opendatakit.org/). Each enumerator pretested the questionnaire on at least two households and the pretests were not included in the data used in the analysis.

In November and December of 2018, the team surveyed 86 households involved in prior improved livestock management activities: 28 for deferred-rotation grazing, 29 for active restoration of degraded lands, and 29 for fodder cropping. Since rangelands were a communal resource, multiple households within a village worked together on the improvements. The team interviewed one person from most of the households. A total of 93 people were interviewed, 30 women and 63 men.

CEADIR used the *snowball method* to find survey respondents (Christopoulos 2009). The field team asked a person familiar with the area to identify farmers who met the selection criteria: 1) membership in the pastoralist association for at least five years before introduction of the improved management practices, 2) participation in livestock production before and after introduction of the improved practices, and 3) involvement in crop production. Then, a team member asked each respondent to identify other farmers that met the criteria. Most respondents were the household head or their spouse responsible for livestock production decisions. All respondents were over 18 years of age and had been involved in crop and livestock farming for at least 10 years. The field team conducted the surveys in person and 90 percent of the contacted households agreed to participate.

The surveyors asked respondents not to answer questions if they were not actively involved in the pilot tests of the improved livestock management practices or could not remember their experience. The surveyors asked respondents to recall information for the five years before the pilot tests and the five years after. Some of the respondents did not have five years of experience in livestock production before and after the pilot tests. Most of the livestock raised by the surveyed households were cattle. Many respondents also owned some goats, sheep, chickens and a few camels. Many also grew multiple crops.

After completion of the household surveys, the field team conducted focus group discussions with each of the pastoralist associations to fill in information gaps. The three associations were unaware of any written reports on the pilot tests. There was no information on the number of households that had tried deferred-rotation grazing or active restoration of degraded pasture land, but stopped before the pilot test ended. There was also no information on the number of households who have continued to use the improved production practices after the pilot ended. As a result of the focus group discussions, the field team concluded that the household survey respondents tended to understate the actual value of their livestock production.

2.3 DATA ANALYSIS

The *financial analysis* reflected the perspective of the livestock farmers and pastoralists, including their benefits from subsidies and their costs of taxes. The *economic analysis* estimated the effects on the national economy and the value of global GHG emission reductions associated with the improved practices. Taxes were included in the financial analysis, but excluded from the economic analysis because these transfer payments benefited others in the national economy. No information was available on the types and value of subsidies in the pilot tests of improved livestock management practices that could have affected the financial analysis results. As usual, the economic analysis priced all inputs and labor at unsubsidized, market prices.

CEADIR valued the GHG emissions reductions at three different values of the social cost of carbon: \$8/tCO_2e in the base case and \$15/tCO_2e and \$25/tCO_2e in the sensitivity analyses. Improved livestock management practices may also have additional economic benefits by reducing other negative environmental impacts. These potential benefits include reduced erosion, water runoff, water and air pollution, biodiversity conservation, and option or existence values. However, CEADIR did not include these extramarket, environmental benefits due to time and budget constraints.

The time horizon for each production practice in the financial analysis varied because it spanned the period needed to implement the improved production practice and the expected duration of the benefits. The expected duration of the benefits was 15 years for deferred-rotation grazing, 16 years for active restoration of degraded land, and 20 years for fodder cultivation. CEADIR estimated the incremental net present value (NPV) compared to the business as usual (BAU) case. The economic analysis used a longer time horizon, 50 years, to reflect the longer duration of the benefits from GHG emission reductions. As a result, the economic analysis included multiple cycles of reinvestment in each of the improved practices. The base case for the financial and economic analyses applied a real discount rate of 12 percent, following USAID CBA guidelines (USAID 2015). CEADIR also conducted sensitivity analyses at two lower real discount rates, 3 percent and 7 percent (the rates that the U.S. Government uses in domestic public investment analyses).

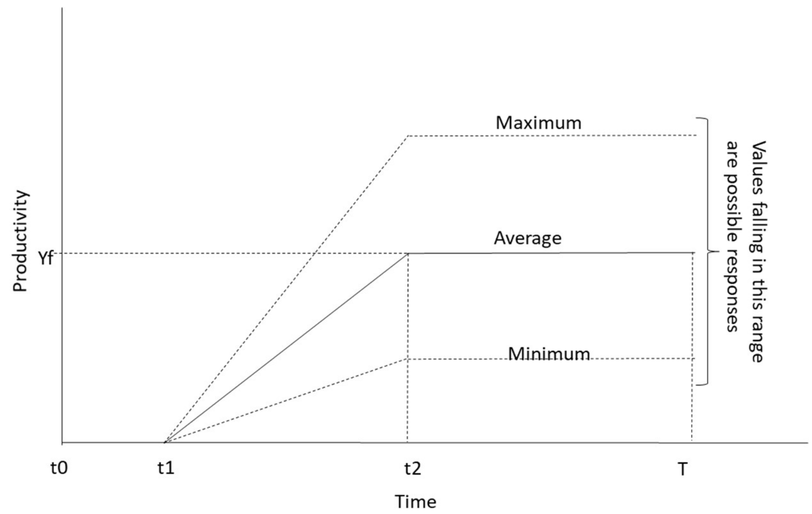
Droughts are common in the Ethiopian lowlands and *moderate* droughts are likely over the time horizon of the financial analysis. The survey data included reported costs and benefits in both drought and nondrought years. Approximately two-thirds of the reported data covered moderate drought years. CEADIR accounted for weather variability risks by averaging the revenues and expenditures across years in the base cases and improved livestock management cases. In moderate droughts, livestock farmers may need to replace animals that die prematurely, but the rest of their production costs would not change much because they still managed their herds and grew crops. In drought years, the costs of moving animals to different grazing sites and obtaining fodder and water may increase, but crop harvesting costs may decrease. Droughts generally have a larger effect on revenues than costs by reducing yields of livestock and agricultural products because the animals may lose weight, fail to grow, reproduce less, or die.

Severe droughts occurred in southern Ethiopia in 1955-57, 1984-85, 2002-03, and 2016-17 (Suryabhagavan 2017; Smith *et al.* 2019). On average, a severe drought occurred every 20 years. Global climate changes may increase the frequency of severe droughts over the historical level. CEADIR addressed the risks of severe drought in the sensitivity analysis. The household survey found that a household could lose 40-60 percent of its cattle in the worst 5 percent of drought instances. CEADIR assumed that a severe drought would kill 60 percent of a livestock herd over a two-year period, and the loss recurred every 20 years. Desta and Coppock (2002) and Project Concern International (2014) have reported similar livestock mortality rates during severe droughts in Ethiopia. CEADIR projected that these losses would occur in years 10-11 and 30-31, assuming that a severe drought lasting two years would occur in 10 years and recur every 20 years. The second year of a severe drought reflected continuing revenue losses and additional costs in buying animals to replenish the herd.

CEADIR estimated the costs and benefits of livestock production per household based on their numbers and types of livestock. The team used the *tropical livestock unit* (TLU) measure to account for differences in food consumption across the various types of livestock (Schwartz *et al.* 1991). One TLU represented 10 sheep, 10 goats, 0.7 cattle, or one camel.

CEADIR assumed a three-phase response function for improved production practices: 1) adoption and early implementation with a time lag before production gains occur; 2) a period of increasing productivity gains; and 3) a plateau after reaching maximum productivity (Figure 2).

FIGURE 2. Probabilistic Linear Plateau Response Function



Source: Beattie *et al.* 2009

The yield increases from improved production practices depend on the type of practice, scale and quality of implementation; frequency of droughts and floods; and the baseline land and water resource degradation.

2.4 BUSINESS-AS-USUAL CASE AND COSTS OF IMPROVED PRACTICES

The BAU case for deferred-rotation grazing and active restoration of degraded land assumed continued livestock grazing on available rangeland without any additional land for grazing during droughts. During moderate droughts, BAU livestock product yields would decrease with pasture availability. The BAU case for fodder cropping assumed that livestock would continue grazing on natural pastures without any supplementation from fodder crops or agricultural residues.

Since CEADIR did not have data on historical production trends in the BAU case, the team assumed that BAU yields would remain constant over time. However, the rangeland in the study area was already degraded, human and livestock populations were rising, and climate change impacts have occurr. It is likely that rangelands would degrade further in the absence of improved production practices. Resource degradation may reduce BAU yields over time in the absence of other changes, such as adoption of more livestock and crop varieties better adapted to degraded land and climate change.

As usual, the CBA attributed costs and revenues to the years when they were expected. The initial costs of implementing an improved production practice were assumed to occur at the beginning of year one. CEADIR assumed that all costs occurred at the beginning of each year and all revenues occurred at the end of the year.

Table 2 lists the main items included in the capital and operating, maintenance, and replacement costs for the three types of improved practices and BAU case. CEADIR included the costs of coordinating farmers to plan and manage the activities in the capital costs.

TABLE 2. Main Items Included in the Capital and Operating, Maintenance, and Replacement Costs for the Improved Practices

Improved Practice	Capital Costs	Operating, Maintenance, and Replacement Costs
A. Deferred-rotation grazing		
Tools and equipment	Hoes, machetes, and axes	Hoes, machetes, and axes
Inputs	Seeds, rhizomes, fencing materials , seedlings, fertilizer, and hay	Hay and fencing materials
Labor	Land preparation, planting, fence construction, harvesting, selective brush clearing, grass seed sowing, and meetings	Herding, grazing, watering, fence maintenance, selective brush clearing
Services	Dewormers	Veterinary medicines and dewormers
Operation	Milking and product marketing	Milking and product marketing
B. Active restoration of degraded rangeland		
Tools and equipment	Hoes, machetes, axes, and sickles	Hoes, machetes, axes, and sickles
Inputs	Seeds, rhizomes, fencing materials, and hay	Hay and fencing materials
Labor	Land preparation, planting, fencing, harvesting, selective brush clearing, sowing grass seed, meetings, water system construction and treatment, and corral construction	Herding andgrazing, watering, fencing, selective brush clearing, meetings, cutting and collecting hay, maintaining fire lines, and maintaining water channels
Services	Veterinary medicines and dewormers	Veterinary medicines and dewormers
Operation	Milking and product marketing	Milking and product marketing
C. Fodder cultivation		
Tools and equipment	Hoes	Hoes
Inputs	Seeds, fencing materials, and manure	Seeds, fencing materials, and manure
Labor	Land preparation, seed collection, transportation, planting, fencing, weeding, herding and grazing, watering, corral construction, and treatment	Seed collection; transportation; planting; fencing; weeding; herding and grazing; watering; corral maintenance; and fodder cutting, carrying, and treatment
Services	Veterinary medicines and dewormers	Veterinary medicines and dewormers
Operation	Harvesting bags, milking, and product marketing	Harvesting bags, milking, and product marketing

The CBA used survey data on current crop and livestock yields and prices, differences in crop and livestock yields with improved production practices, the investment period for the three improved practices, number of years before improved practices begin increasing crop and livestock yields, and year of the peak yield response from improved practices. Hired labor and unpaid household labor were both valued at the local wage rates for each type of activity. Workers in the study area can be hired for a full day or a *short task* that typically lasts a quarter of a day and earns 25 percent of the daily wage rate. CEADIR assumed that future prices of inputs, labor costs, and products would increase 1 percent per year in *real terms* (beyond the inflation rate). Table 3-8 present the inputs and unit costs used in the implementation and operational phases of the improved practices.

TABLE 3. Inputs and Unit Costs for the Implementation Phase of Deferred-Rotation Grazing

Item	Units	Baseline Activity	Improved Activity	Change	Unit Price (U.S. Dollars)
Hoes	Count	3	72.5	69.5	2.87
Machetes	Count	1	2.9	1.9	1.79
Axes	Count	1	3	2	0.72
Seeds	Kg	65.5	104.8	39.3	2.55
Rhizomes/cuttings	Kg	0	2.5	2.5	0.43
Fencing materials	Count	2.3	2.1	-0.3	1.79
Fencing post	Count	0	5	5	0.36
Seedlings	Count	0	3	3	3.59
Harvesting bags	Count	0	12	12	0.54
Veterinary medicine	Liters	21.3	33.5	12.2	4.95
Dewormers	Strips/Tablets	32	7.4	-24.6	0.26
Hay	Bales	0	180	180	10.76
Opening new land	Short tasks	0	27	27	1.79
Land preparation	Short tasks	0	31.0	31.0	1.79
Planting	Short tasks	0	16.8	16.8	1.79
Fencing	Short tasks	0	29.6	29.6	1.79
Harvesting	Short tasks	0	38.4	38.4	1.79
Selective bush clearing	Short tasks	0	0	0	1.79
Sowing grass	Short tasks	0	17.1	17.1	1.79
Meetings	Short tasks	102	112	10	1.79

TABLE 4. Inputs and Unit Costs for the Operational Phase of Deferred-Rotation Grazing

Item	Units	Baseline Activity	Improved Activity	Change	Unit Price (U.S. Dollars)
Hoes	Count	0	3	3	2.87
Machetes	Count	1	2.9	1.9	1.79
Hay	Bales	0	84	84	10.76
Fencing materials	Count	0	2.08	2.08	1.79
Fencing post	Count	0	5	5	0.36
Veterinary medicine	Liters	21.3	33.5	12.2	3.51
Dewormers	Strips/Tablets	32	7.4	-24.6	0.23
Deworming	Short tasks	25	12	-13	7.17
Health prophylaxis	Short tasks	15	13.5	-1.5	7.17
Health treatments	Short tasks	34.1	58.1	23.9	7.17
Herding on shared rangeland	Short tasks	302.6	247.1	-55.5	1.79
Herding on own land	Short tasks	356.7	340.9	-15.8	1.79
Watering	Short tasks	166.0	141.4	-24.6	1.79
Fencing	Short tasks	0	29.6	29.6	1.79
Housing maintenance	Short tasks	2	2.3	0.3	1.79
Selective bush clearing	Short tasks	0	36.2	36.2	1.79
Meetings	Short tasks	112.5	140.2	27.7	1.79
Feeding	Short tasks	152.9	190.8	37.9	1.79
Clearing brush	Short tasks	0	2	2	1.79
Burning brush	Short tasks	0	2	2	1.79

TABLE 5. Inputs and Unit Costs for the Implementation Phase of Active Restoration of Degraded Rangeland

Item	Units	Baseline Activity	Improved Activity	Change	Unit Price (U.S. Dollars)
Hoes	Count	0	2.1	2.1	2.82
Machetes	Count	1	2.7	1.7	1.76
Axes	Count	1	3.5	2.5	2.82
Sickles	Count	1	2.5	1.5	1.76
Seeds	Kg	0	1.5	1.5	1.06
Rhizomes/cuttings	Count	0	2	2	2.64
Fencing materials	Count	1	1.6	0.6	2.64
Veterinary medicine	Liters	21.4	8.3	-13.1	0.35
Dewormers	Strips	18.7	70	51.3	3.52
Hay	Bales	20	120	100	10.56
Opening new land	Short tasks	0	16	16	2.25
Land preparation	Short tasks	0	20	20	2.25
Planting	Short tasks	0	1	1	2.25
Fencing	Short tasks	10	29.6	19.6	2.25
Harvesting	Short tasks	0	38.4	38.4	2.25
Bush clearing	Short tasks	0	0	0	2.25
Sowing grass	Short tasks	0	17.1	17.1	2.25
Meetings	Short tasks	2	12	10	2.25
Herding on shared land	Short tasks	357.5	357.5	0	1.69
Herding on own land	Short tasks	334	334	0	1.69
Watering	Short tasks	149.5	149.5	0	1.69
Health treatments and prophylaxis	Short tasks	51.6	58.7	7.1	1.69
Constructing corrals	Short tasks	0	5	5	1.69

TABLE 6. Inputs and Unit Costs for the Operational Phase of Active Restoration of Degraded Rangeland

Item	Units	Baseline Activity	Improved Activity	Change	Unit Price (U.S. Dollars)
Hoes	Count	0	2.1	2.1	2.82
Machetes	Count	1	2.7	1.7	1.76
Sickles	Count	1	2.5	1.5	1.76
Hay	Bales	0	120	120	2.75
Fencing materials	count	0	1.5	1.5	2.64
Veterinary medicine	Liters	21.3	7	-14.3	1.76
Dewormers	Strips/Tablets	32	7.4	-24.6	0.35
Herding on shared rangeland	Short tasks	357	357	0	1.69
Herding on own rangeland	Short tasks	356.7	340.9	-15.8	1.69
Watering	Short tasks	149.5	107.3	-42.2	1.69
Fencing	Short tasks	4	16	12	2.25
Selective bush clearing	Short tasks	0	4	4	2.25
Meetings	Short tasks	2	12	10	2.25
Feeding	Short tasks	0	15	15	2.25
Clearing brush	Short tasks	0	1.5	1.5	2.25
Burning brush	Short tasks	0	1.5	1.5	2.25
Deworming	Short tasks	25	12	-13	2.25
Health treatments and prophylaxis	Short tasks	49.4	71.6	22.1	2.25
Hay collection	Short tasks	0	3	3	2.25
Digging fire lines	Short tasks	0	1	1	2.25

Hay purchases constituted a substantial share of the cost of the implementation stage of deferred-rotation grazing and active restoration of rangeland. The pastoralist associations did not continue full operations of the improved practices for the period of potential effectiveness. Neverthless, many of the surveyed farmers continued to purchase some hay after the pilot tests ended, but in small amounts that could only feed a typical herd for a short period of time during a normal dry season or moderate drought year. Agropastoralists may be able to survive more frequent or more severe droughts with additional investments to increase access to hay and water.

TABLE 7. Inputs and Unit Costs for the Implementation Phase of Fodder Cultivation

Item	Units	Baseline Activity	Improved Activity	Change	Unit Price (U.S. Dollars)
Hoes	Count	5	5	0	1.76
Seeds	Kg	23.0	27.4	4.4	0.52
Fencing materials	Count	4.5	2.25	-2.25	3.52
Veterinary medicine	Liters	5.6	2.7	-2.9	2.35
Dewormers	Strips	113.3	192	78.7	0.19
Manure	Load	5	10	5	0.35
Salt	Kg	53.4	130.3	76.9	0.29
Fencing posts	Count	0	10	10	0.35
Opening new land	Short tasks	10	73	63	1.69
Land preparation	Short tasks	26.1	23.8	-2.3	1.69
Seed search	Short tasks	3.03	3.03	0	1.69
Transportation	Short tasks	2.35	2.8	0.4	1.69
Planting	Short tasks	13.93	9.5	-4.43	1.69
Fencing	Short tasks	14.9	13.4	-1.6	1.69
Weeding	Short tasks	16.5	50.3	33.9	1.69
Herding on own land	Short tasks	365	365.5	0.5	1.69
Watering	Short tasks	147.7	141.5	-6.2	1.69
Corral construction	Short tasks	4.2	4	-0.2	1.69
Health prophylaxis	Short tasks	12	12.1	0.1	1.69
Health treatment	Short tasks	45.9	41.9	-4.1	1.69

TABLE 8. Inputs and Unit Costs for the Operational Phase of Fodder Cultivation

Item	Units	Baseline Activity	Improved Activity	Change	Unit Price (U.S. Dollars)
Hoes	Count	5	5	0	1.76
Seeds	Kg	23.0	27.4	4.4	0.52
Fencing materials and posts	Count	4.5	2.3	-2.3	1.76
Veterinary medicine	Liters	5.6	2.7	-2.9	2.35
Dewormers	Strips	113.3	192	78.7	0.19
Manure	Load	0	10	10	0.35
Salt	Kg	53.4	130.2	76.8	0.07
Seed search	Short tasks	3	3	0	1.69
Transportation	Short tasks	2.4	2.8	0.4	1.69
Planting	Short tasks	13.9	9.5	-4.4	1.69
Fencing	Short tasks	4.9	3.4	-1.6	1.69
Weeding	Short tasks	46.5	50.3	3.9	1.69
Herding on own land	Short tasks	365.9	365.5	-0.4	1.69
Watering	Short tasks	147.7	141.5	-6.2	1.69
Housing maintenance	Short tasks	4.2	4	-0.2	1.69
Cut and carry fodder	Short Days	0	10	10	1.69

Table 9 lists the incremental costs of the improved production practices above the amounts required for the BAU case.

TABLE 9. Incremental Costs of the Improved Practices (U.S. Dollars Per Household)

Improved Practice	Incremental Implementation Costs (Year 1)	Incremental Operating Costs (Year 4)
A. Deferred-rotation grazing		
Machinery and equipment	204	12
Inputs	2,111	976
Labor	0	70
Services	305	74
Taxes	262	0
Total	**$2,882**	**$1,131**
B. Intensive restoration of degraded rangeland		
Machinery and equipment	19	12
Inputs	1,241	309
Labor	296	32
Services	0	0
Taxes	155	0
Total	**$1,710**	**$352**
C. Fodder cultivation		
Machinery and equipment	0	0
Inputs	29	16
Labor	0	0
Services	134	3
Taxes	16	0
Total	**$180**	**$18**

2.5 YIELD AND REVENUE ASSUMPTIONS

Table 10 describes the timing and duration of yield increases from the improved practices and the product prices used in the analysis. The team obtained information on the timing and magnitude of the yield gains from the improved practices from the survey and focus group discussions.

TABLE 10. Timing and Duration of Yield Increases from the Improved Practices and the Product Prices

Improved Practice	Product	Unit	First Year of Improved Yield	Peak Year for Improved Yield	Average Annual Yield: BAU	Average Annual Yield: Improved Practices	Increase in Average Annual Yield with Improved Practices	Product Prices, (2018 U.S. Dollars)
Deferred-rotation grazing (15-year benefit period)	Cow's milk	Kg	2	4	1,335.3	1,866.6	531.3	0.39
	Goat milk	Kg	2	3	191.6	602.1	410.5	0.47
	Camel milk	Kg	2	5	408.3	786.7	378.4	0.18
	Chicken eggs	Each	2	3	250.0	390.0	140.0	0.07
	Cattle	Each	2	4	1.0	1.9	0.9	672.65
	Goats	Each	2	3	6.5	11.0	4.5	71.75
	Sheep	Each	2	3	7.5	13.0	5.5	71.75
Intensive restoration of degraded rangeland (16-year benefit period)	Cow's milk	Kg	2	4	1,084.0	1,698	614.00	0.42
	Goat milk	Kg	2	3	105.1	382.5	277.4	0.53
	Camel milk	Kg	2	5	1056.2	1064.0	7.7	0.18
	Chicken eggs	Each	2	3	0	1600	1600	0.07
	Cattle	Each	2	4	2.0	3.0	1.0	387.32
	Goats	Each	2	3	9.0	14.0	5.0	52.82
	Sheep	Each	2	3	8.5	13.0	4.5	52.82
Fodder cultivation (benefit period))	Cow milk	Kg	2	4	828.8	1,208.0	379.1	0.42
	Goat milk	Kg	2	3	285.6	306.7	21.1	0.53
	Maize kernels	Quintal	2	5	7.2	21.7	14.5	1.41
	Maize stover	Load	2	3	0.0	3.5	3.5	0.07
	Green maize residue	Load	2	4	0.0	15.3	15.3	0.35
	Rhodes grass (*Chloris gayana*)	Load	2	4	0.0	0.5	0.5	1.41
	Cattle	Each	2	3	1.0	1.5	0.5	387.32
	Goats	Each	2	3	6.0	9.0	3.0	52.82

CEADIR calculated the expected value of net revenues, reflecting the probabilities of normal rainfall and drought years and their effects on average yield. Table 1 shows the expected net revenues from maize production, reflecting normal and drought years.

TABLE 2. Expected Value of Net Revenues from Maize Production

Item	Normal Rainfall Year	Drought Year
Maize yield (t/ha)	1.5	0.7
Farmgate price for maize (U.S. $/t)	350	500
Gross revenues (U.S. $/ha)	525	350
Maize production costs (U.S. $/ha)	70	70
Net revenues (U.S. $/ha)	455	280
Probability	0.6	0.4
Net revenues x probability (U.S. $/ha)	273	112
Expected value of net revenues (U.S. $/ha)	385	

2.6 IMPACTS ON GREENHOUSE GAS EMISSIONS

Improved livestock production practices can have positive and negative impacts on GHG emission reductions. The positive impacts occur because improvements in rangeland quality allow more carbon sequestration and storage in the soil. Potential negative effects stem from increases in the ruminant livestock population, which increases enteric emissions of methane. Increases in livestock product yields per animal could reduce methane emissions by allowing farmers to reduce their herd size, particularly where intensive production methods make raising livestock expensive. However, it is unlikely that small-scale livestock producers in Ethiopia would reduce their herd sizes if product yields increase because they typically view livestock as a store of wealth.

Carbon stocks generally increase on rangelands after more productive grass species are planted and degraded lands are restored. Vegetation sequesters atmospheric carbon, which is then stored in above- and below-ground plant parts or incorporated into soil organic matter. In turn, more organic matter can improve the soil structure, water infiltration rates, and aeration for better rooting and growth of rangeland vegetation and crops. More plant litter on the soil surface can reduce soil erosion and improve moisture retention. Conant *et al.* (2017) reviewed 126 recent articles on soil carbon stocks in grasslands under different management regimes and estimated that rangeland grasses sequestered an additional 1.72 tCO_2e/ha per year when management improved.

CEADIR estimated the increased carbon sequestration from the three improved production practices by obtaining soil carbon sequestration rates from other studies. Under the Intergovernmental Panel on Climate Change (IPCC) classification system, this is a tier 1 estimation method. The team did not have the resources needed to use more complicated methods such as measuring soil carbon changes or using process models.

Deferred-rotation grazing and active restoration of rangeland are applied under similar land and vegetation conditions and lead to similar productivity gains. CEADIR assumed that these soil carbon sequestration increases would continue at a constant rate for 20 years and then end. For these two improved practices, CEADIR applied the average rate of soil carbon sequestration from Conant *et al.* (2017) for grasslands with improved management. The team multiplied this rate by the average number of hectares participating households devoted to each of these improved production practices in the pilot tests in the Oromia lowlands. The annual increase in the soil carbon stock per participating household was 4.3 tCO_2e for deferred-rotation restoration and 0.9 tCO_2e for active restoration.

In southern Ethiopia, farmers often cultivated fodder on grassy buffers around farm fields to help protect crops from livestock grazing and trampling. Fodder cultivation areas also benefited from the manure deposited directly by grazing livestock and nutrient runoff from the farm. As a result, fodder cultivation areas typically had higher baseline productivity and soil organic content than rangelands. Much of the cultivated fodder was from maize planted in tilled soil and tilling reduces soil carbon stocks. Because of the prior vegetative cover in the fodder cropping areas and the soil disturbance from tillage, CEADIR assumed that fodder cultivation would not have any additional soil carbon sequestration benefits.

The households participating in the Oromia lowland pilots of the improved practices increased their total annual livestock production and average herd sizes. The net impact on GHG emissions accounted for any reductions from soil carbon sequestration and the increases from ruminant livestock methane emissions. Although it is possible to increase the efficiency of livestock production without increasing livestock populations, that was not the case in these three pilot tests.

CEADIR used IPCC (2006) estimates of methane emission rates for four types of livestock in Africa.[7] This analysis used the IPCC (2014) value of 28 for the *global warming potential* of methane relative to carbon dioxide. CEADIR estimated that the higher ruminant livestock production would increase annual livestock methane emissions per household by 2.18 tCO_2e for deferred-rotation grazing, 2.20 tCO_2e for active restoration of degraded rangeland, and 0.85 tCO_2e for fodder cropping.

These increases in methane emissions would continue as long as ruminant livestock populations remain higher (unless other methods for reducing methane emissions per animal are adopted). Eventually, the negative impacts of increased methane emissions can outweigh the benefits of soil carbon sequestration and storage from deferred-rotation grazing and active restoration of rangelands. The negative impacts of fodder cultivation on GHG emissions would begin as soon as ruminant livestock populations increased since this production practice would not increase carbon sequestration.

[7] IPCC (2006) Tables 10.10 and 10.11

3. RESULTS OF THE FINANCIAL AND ECONOMIC ANALYSES

3.1 FINANCIAL ANALYSIS PER HOUSEHOLD

Table 3 contains the financial NPVs for the BAU case and the improved practices at a 12 percent real discount rate. The time horizons for the financial analysis reflected the time required to implement the improved practices (2-4 years) and the duration of the benefits for livestock production (14-17 years). Accounting for both factor, the time horizons for the financial analysis ranged from 16-21 years.

The NPVs of the BAU cases varied because they pertained to different pilot test areas. At the 12 percent discount rate, the BAU cases generated a high, positive NPV for the Dadim Pastoralist Association, a low positive NPV for the Harweyu Pastoralist Association, and a small, negative NPV for the Dharito Pastoralist Association.

There are several reasons why it may be financially rational for farmers to continue a BAU activity when a financial analysis indicates a negative NPV. They may have already incurred sunk costs that cannot be recovered. Farmers may place a lower value on unpaid, household labor time than the wage rate assumed in the analysis. Farmers may have a lower, implicit time value of money than the discount rate in the analysis.

A financial analysis could also have a negative NPV for the BAU case if the data came from respondents who deliberately underestimated their revenues or overestimated their costs or had difficulty recalling long-term information accurately. Furthermore, the financial analysis results for the BAU alternatives could also be different if applied in other locations.

TABLE 3. Financial NPVs of the BAU Case and the Improved Practices at a 12 Percent Discount Rate

Improved Practice	Net Present Value of the BAU Case (U.S. Dollars Per Household)	Net Present Value of the Improved Practice (U.S. Dollars Per Household)
Deferred-rotation grazing	$3,153	$1,740
Active restoration of degraded land	$216	$3,130
Fodder cultivation	-$64	$2,235

Table 4 shows the financial NPVs of the improved practices at the 12 percent discount rate and the payback periods. The incremental NPVs were calculated by subtracting the NPVs for the BAU from the total NPVs for each of the improved production practices. At this relatively high discount rate, deferred-rotation grazing had a large, negative NPV compared to the BAU case. Both active restoration of degraded land and fodder cultivation had large, positive incremental NPVs over the period of the analysis.

TABLE 4. Financial NPVs of the Improved Practices at a 12 Percent Discount Rate and the Payback Periods

Improved Practice	Net Present Value (U.S. Dollars Per Household)	Payback Period (Years)
Deferred-rotation grazing	-$1,413	12
Active restoration of degraded land	$2,914	6
Fodder cultivation	$2,299	4

The *payback period* is a less sophisticated criterion for financial decision making than the NPV because it does not apply a discount rate for the time value of money or count any future benefits after the breakeven year for an investment. The relatively long, 12-year payback period for deferred-rotation grazing is consistent with the negative NPV for this production practice. Although the NPVs for intensive restoration of degraded rangeland and fodder cultivation were positive, their four- and six-year payback periods may still be too long to interest associations of low-income pastoralists in the absence of financing.

Table 5 shows the financial NPVs of the improved practices at the three real discount rates. Use of the lower discount rates increased the incremental NPVs of all three practices.

TABLE 5. Financial NPVs of the Improved Practices by Discount Rate (2018 U.S. Dollars Per Household)

Practice	12 Percent Discount Rate	7 Percent Discount Rate	3 Percent Discount Rate
Deferred-rotation grazing	-$1,413	-$149	$1,535
Active restoration of degraded land	$2,914	$5,155	$8,060
Fodder cultivation	$2,299	$3,654	$5,561

The incremental NPV for deferred-rotation grazing was negative because participating livestock producers had to purchase hay to feed their livestock while the pasture land rested and recovered. In the first year of active restoration, the participating households spent an average of $1,937 on hay purchases. They continued purchasing hay after the rangeland recovered, but the average cost per household decreased to $907 in the first year after the rangeland was restored. The households participating in deferred-rotation grazing increased their annual production by an average of 0.9 cattle, 4.5 goats, and 5.5 sheep. Since households in the study area commonly viewed livestock as a store of wealth, they were willing to make the tradeoff of buying hay to increase livestock production over the 15-year period.

Active restoration of degraded land had lower capital and continuing cost than deferred-rotation grazing. The capital costs were $1,710 per household. The cost of purchasing hay while the land was being restored was $1,056 per household and this was the largest cost item. However, the costs in year 4 were only $615 per household. Active restoration allowed households to increase production of cattle, goats, sheep, milk from all three of these types of livestock, and chicken eggs. The incremental benefit was $1,451 per household in year 4 and continued to rise over the 16-year period of analysis.

The BAU for fodder cultivation was low-input, low-output herding. Approximately 96 percent of the operating costs in this BAU case were labor for herding and milking. The fodder cultivation pilot increased labor requirements for weeding and cutting and carrying fodder. However, the annual cost increase was only $170 per household in year 4, when the practice change was fully implemented. The annual incremental benefits were substantially higher at $560 per household in year 4. **Error!**

Reference source not found. to 5 show the time pattern of the financial net benefits over the period of analysis for each of the improved

FIGURE 3. Financial Net Benefits of Deferred-Rotation Grazing by Year (U.S. Dollars Per Household)

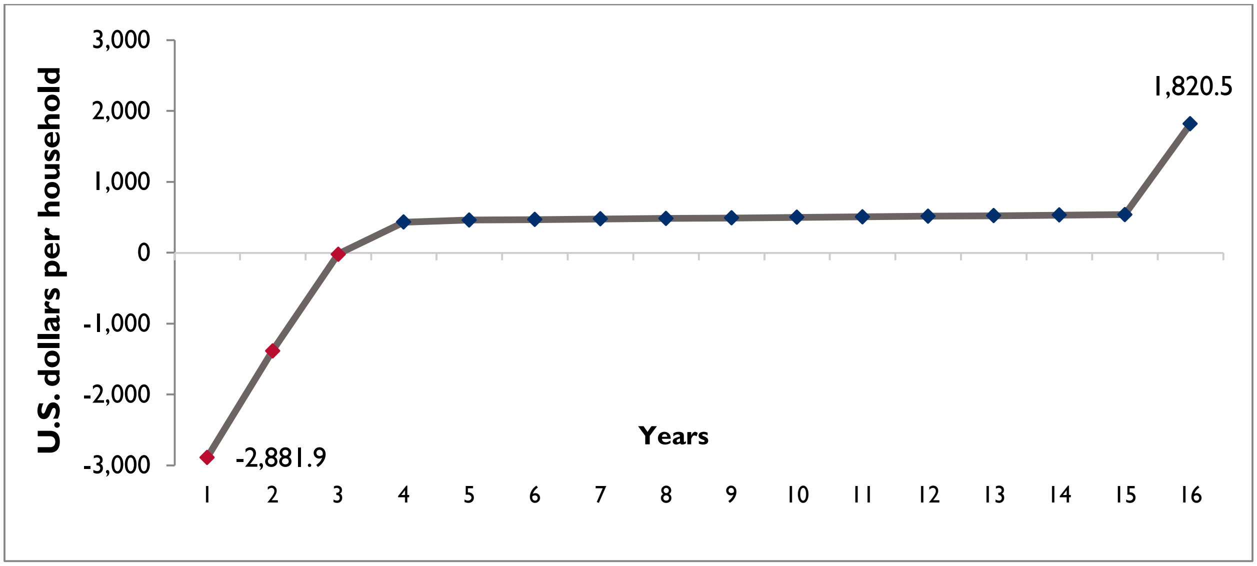


FIGURE 4. Financial Net Benefits of Active Restoration of Degraded Rangelands by Year (U.S. Dollars Per Household)

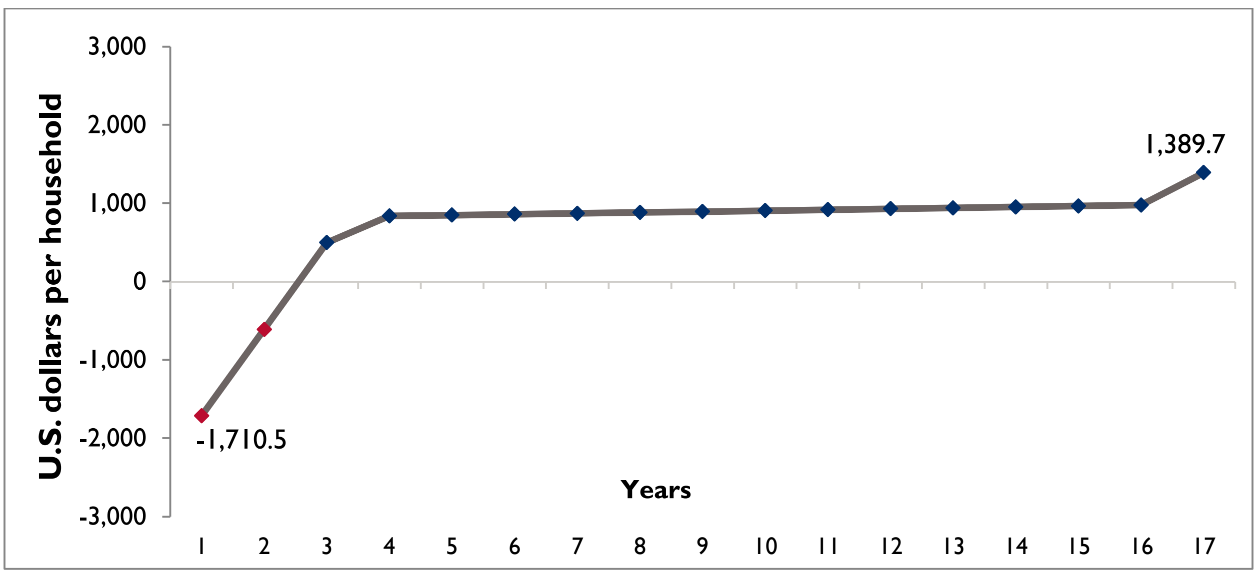
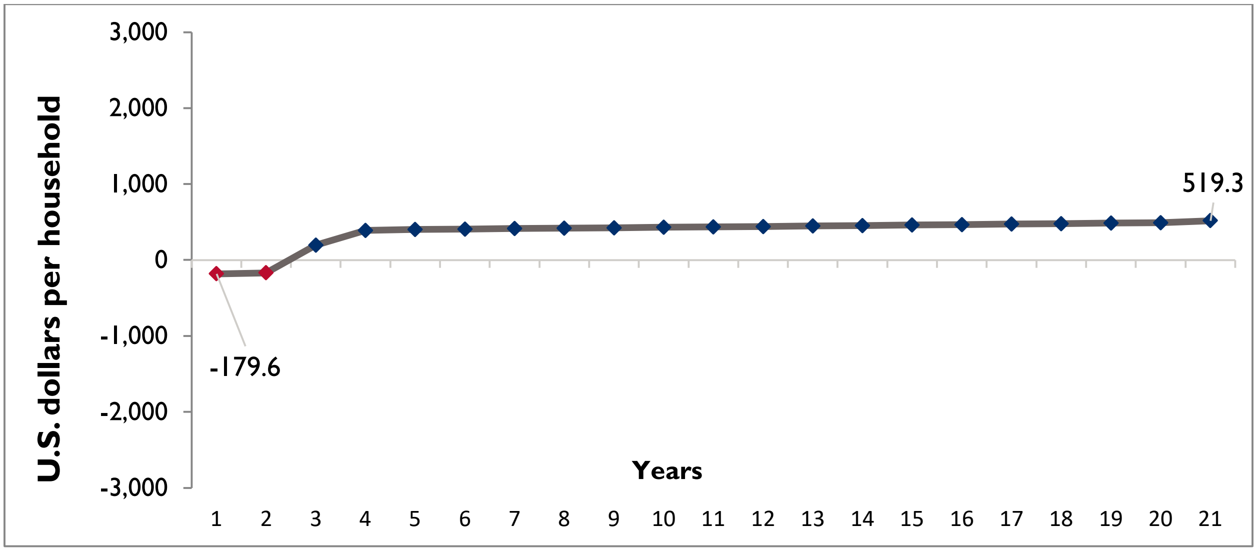


FIGURE 5. Financial Net Benefits of Fodder Cultivation by Year (U.S. Dollars Per Household)



3.2 ECONOMIC EFFECTS PER HOUSEHOLD, EXCLUDING THE SOCIAL COST OF GHG IMPACTS

Table 6 contains the economic NPVs of the improved practices at the three discount rates. The 50-year time horizon involved multiple investment cycles. The economic analysis excluded any subsidies and taxes. This table does not include the social costs of GHG emissions.

TABLE 6. Economic NPVs of Improved Practices by Discount Rate (U.S. Dollars Per Household)

Discount Rate	Deferred-Rotation Grazing	Active Restoration of Degraded Rangeland	Fodder Cultivation
3 percent	$2,578	$15,414	$8,777
7 percent	$11	$6,987	$4,330
12 percent	-$1,237	$3,193	$2,266

At the 12 percent discount rate, extending the time horizon to 50 years and removing taxes and subsidies did not significantly change the NPVs of any of the improved practices. The incremental economic gains for all three improved practices were higher at the lower discount rates. For deferred-rotation grazing the incremental NPV was negative at the 12 percent discount, close to zero at the 7 percent discount rate, and positive at the 3 percent discount rate. Active restoration of degraded rangelands and fodder cropping had positive NPVs at all three discount rates.

3.3 IMPACT OF SEVERE DROUGHT RISKS ON THE ECONOMIC EFFECTS PER HOUSEHOLD, EXCLUDING THE SOCIAL COST OF GHG IMPACTS

Table 7 compares the impact of normal rainfall with moderate droughts and severe droughts on the economic NPVs over 50 years at a 12 percent discount rate. Severe droughts substantially reduced the economic NPVs for all of the improved practices. Even though the NPVs for active restoration of rangeland and fodder cultivation were positive, **Error! Reference source not found.** show that households that have adopted any of the improved practices would encounter many years with large economic losses. These losses can negative affect the health of members of livestock-producing households (Smith *et al.* 2019).

TABLE 7. Impact of Normal Rainfall With Moderate Droughts and Severe Droughts on Economic NPVs Over 50 Years at a 12 Percent Discount Rate (U.S. Dollars Per Household)

Weather Pattern	Deferred-Rotation Grazing	Active Restoration of Degraded Rangeland	Fodder Cultivation
Mix of normal rainfall and moderate droughts	-$1,404	$2,937	$2,193
Mix of normal rainfall, moderate droughts, and severe droughts	-$3,405	$1,152	$1,515

FIGURE 6. Discounted Economic Net Benefits by Year for Deferred-Rotation Grazing With Severe Drought Risks, at a 12 Percent Discount Rate (U.S. Dollars Per Household)

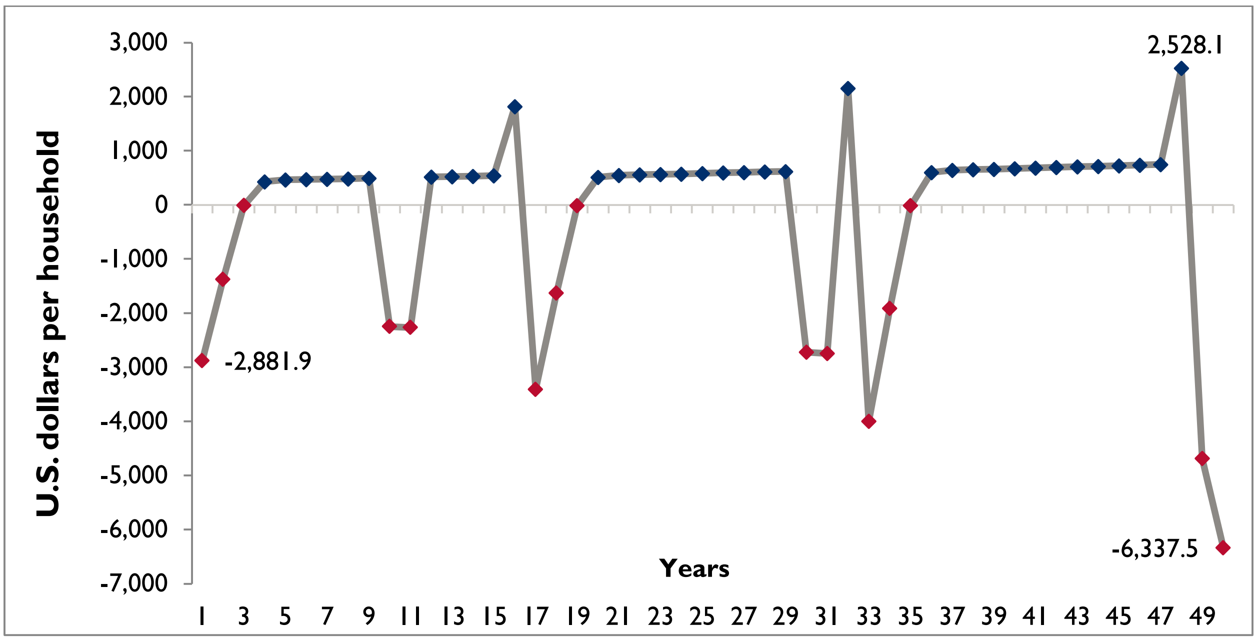


FIGURE 7. Discounted Economic Net Benefits by Year for Active Restoration of Degraded Rangeland With Severe Drought Risks, at a 12 Percent Discount Rate (U.S. Dollars Per Household)

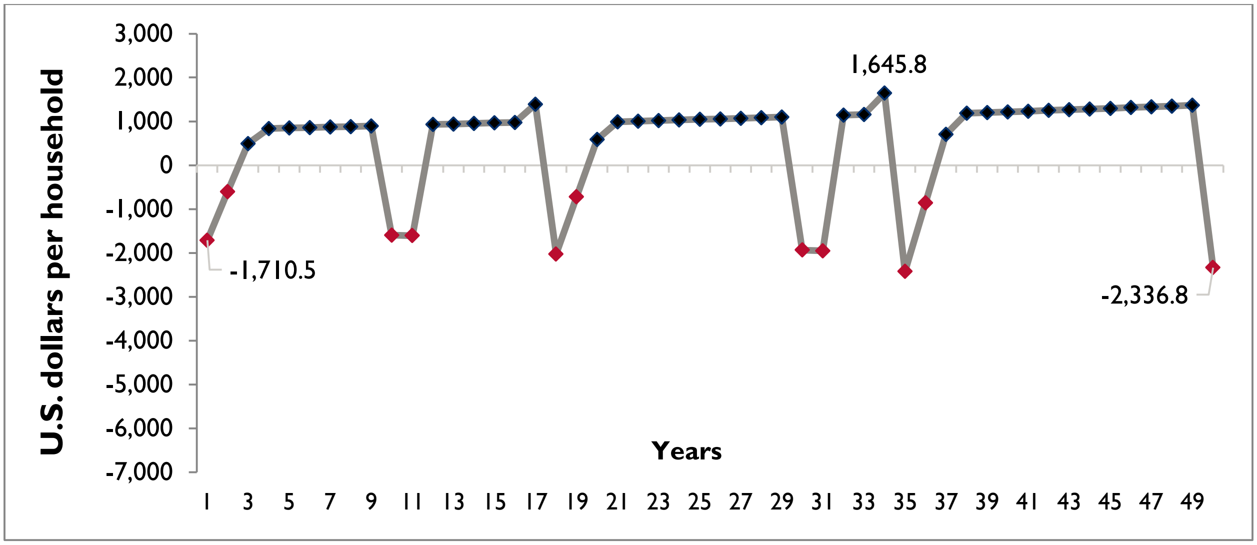
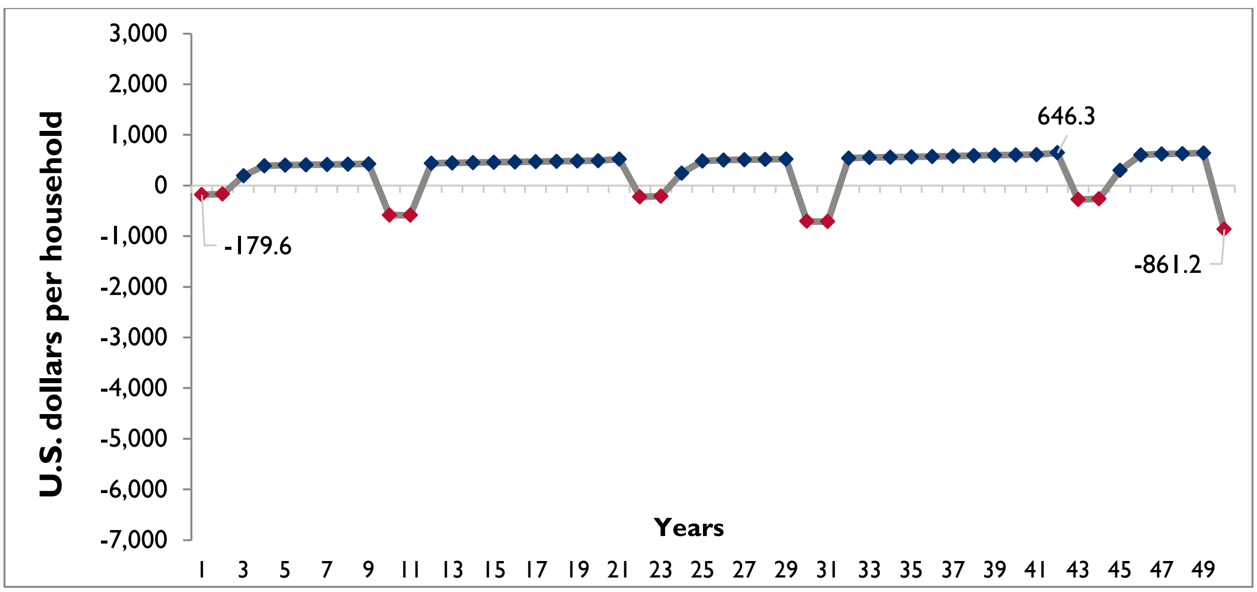


FIGURE 8. Discounted Economic Net Benefits by Year for Fodder Cultivation With Severe Drought Risks, at a 12 Percent Discount Rate (U.S. Dollars Per Household)



3.4 ECONOMIC ANALYSIS PER HOUSEHOLD, INCLUDING THE SOCIAL COST OF GHG IMPACTS

Figures 9 to 11 show the discounted annual economic returns for the improved practices, including the social cost of GHG emission over 50 years. CEADIR valued GHG emissions at \$8.00/tCO_2e in the base case, and at \$15/tCO_2e and \$25/tCO_2e in the sensitivity analysis. The periodic negative returns occurred when the livestock farmers had to repeat their capital investments to renew the cycle of improved production practices.

FIGURE 9. Discounted Net Economic Benefits With the Social Cost of GHG Emissions for Deferred-Rotation Grazing by Year at Three Discount Rates (U.S. Dollars Per Household)

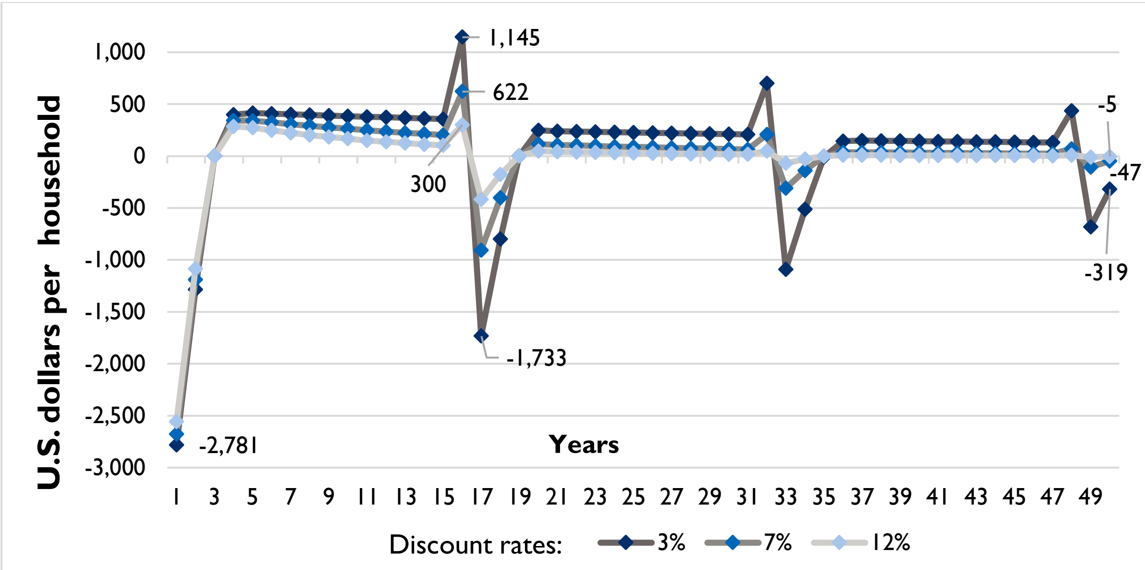


FIGURE 10. Discounted Net Economic Benefits With the Social Cost of GHG Emissions for Active Restoration of Degraded Rangeland at Three Discount Rates (U.S. Dollars Per Household)

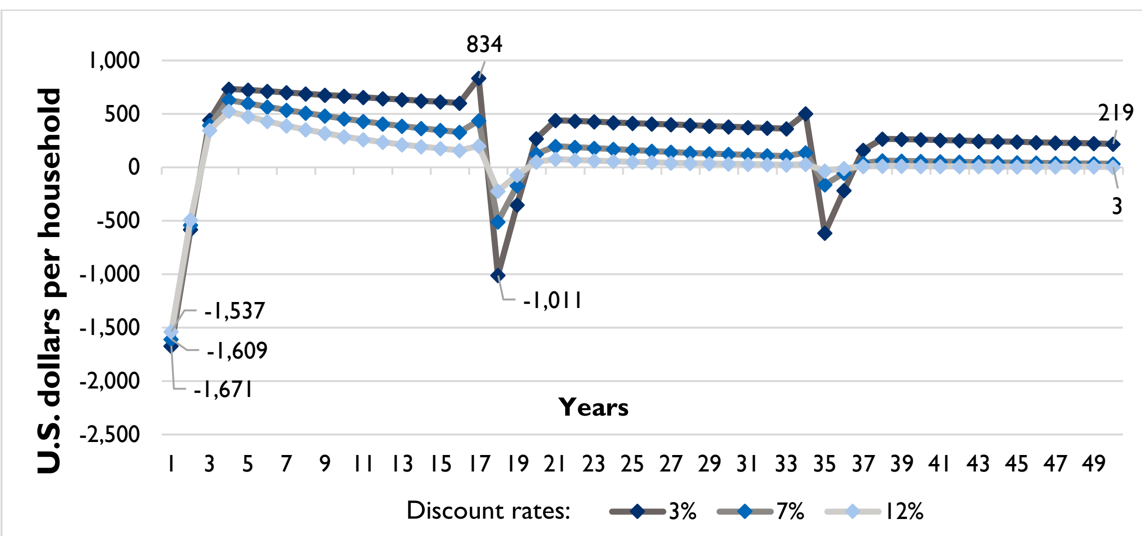


FIGURE 11. Discounted Net Economic Benefits With the Social Cost of GHG Emissions for Fodder Cultivation at Three Discount Rates (U.S. Dollars Per Household)

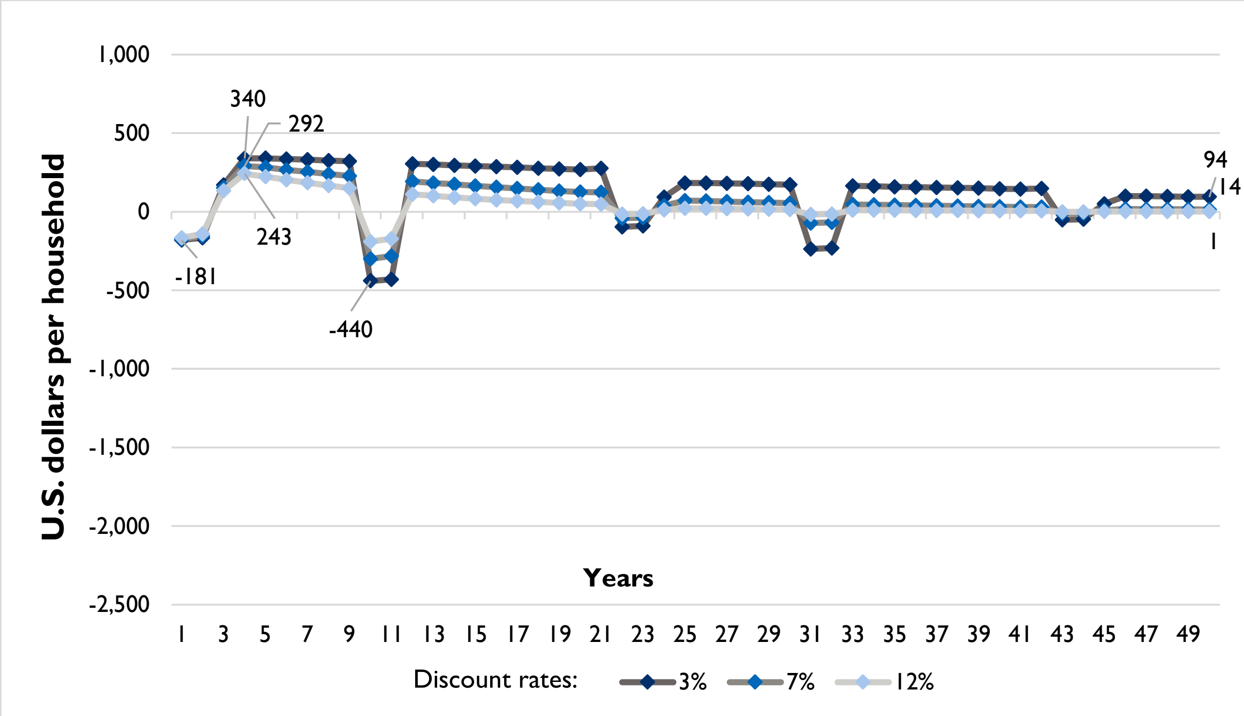


Table 8 contains the economic NPVs for the GHG impacts over 50 years at a social cost of carbon of $8/tCO$_2$e and the three discount rates. Deferred-rotation grazing increased soil carbon storage and was only associated with a small increase in methane emissions from an increase in ruminant livestock populations in the pilot test. However, active restoration of rangeland and fodder cultivation were associated with larger increases in ruminant herd sizes and the increases in methane emissions outweighed the reductions in carbon dioxide emissions.

TABLE 8. Economic NPVs for the GHG Impacts at a Social Cost of Carbon of $8.00/tCO$_2$e and Three Discount Rates (U.S. Dollars Per Household)

Production Practice	3 Percent Discount Rate	7 Percent Discount Rate	12 Percent Discount Rate
Deferred-rotation grazing	$64	$124	$113
Active restoration of degraded rangeland	-$350	-$170	-$95
Fodder cultivation	-$176	-$94	-$57

Table 9 lists the economic NPVs for the GHG impacts of the improved practices at the three carbon prices and the 12 percent discount rate over 50 years. Deferred-rotation grazing reduced the present value of the social cost of GHG emissions. Active restoration of degraded rangeland and fodder cultivation increased the present value of the social cost of GHG emissions.

TABLE 9. Economic NPVs for the GHG Impacts at Three Values of the Social Cost of Carbon and a 12 Percent Discount Rate (U.S. Dollars Per Household)

Practice	$8 tCO$_2$e	$15 tCO$_2$e	$25 tCO$_2$e
Deferred-rotation grazing	$113	$211	$352
Active restoration of degraded rangeland	-$95	-$177	-$295
Fodder cultivation	-$57	-$106	-$177

Table 10 contains the total economic NPV of each production practice per household, including the social cost of GHG emissions. The relative magnitudes of values show the same pattern across practices and discount rates as seen in financial value per household over the life of each practice, shown in Table 10. Although transfer payments are a relatively small part of the cash flow of each activity, excluding transfer payments from costs makes economic values significantly higher than financial values, especially at low discount rates and over long time horizons.

TABLE 10. Total Economic NPVs of the Improved Practices Including the Social Cost of GHG Impacts at a Social Cost of $8.00/tCO2e and Three Discount Rates (U.S. Dollars Per Household)

Practice	12 Percent Discount Rate	7 Percent Discount Rate	3 Percent Discount Rate
Deferred-rotation grazing	-$1,404	-$230	$2,069
Active restoration of degraded rangeland	$2,937	$6,612	$14,767
Fodder cultivation	$2,121	$4,086	$8,316

3.5 ECONOMIC ANALYSIS OF SCALING UP THE PILOTS TO THE NATIONAL LEVEL

This section estimates the economic impacts of expanding the three small pilots of improved livestock production practices to the national scale. Ethiopia's rural population was approximately 78 million in 2019. Shapiro *et al.* (2017) estimated that 14 million ha of arid and semi-arid land was grazed in Ethiopia and the average area devoted to fodder crops was 1.74 ha per household. Although much of the country is too arid for most commercial crops, some of the grazing land could support fodder cultivation. According to Rettberg *et al.* (2017), most of the rangeland in Ethiopia was already degraded. In the analysis below, CEADIR assumed that 25-50 percent of the arid and semi-arid grazing land could be restored (3.5-7.0 million ha).

The three improved practices discussed in this CBA are mutually exclusive alternatives. In other words, only one of these improved practices could be implemented at a particular site. Table 11 presents the economic NPVs of scaling up the three improved practices to 3.5 million ha at a 50-year time horizon and 12 percent discount rate. If the land area is expanded to 7.0 million ha, the numbers in Table 20 can be doubled. There would be substantial positive economic benefits from scaling up active restoration of degraded rangeland and fodder cultivation. However, scaling up deferred-rotation grazing would have negative economic benefits if the BAU case for the single pilot test of this production practice in the one location analyzed is the relevant comparison for the nationwide incremental benefit calculations. Since deferred-rotation grazing had a negative NPV, CEADIR assumed that active restoration of degraded rangeland and fodder cultivation could be implemented on the 3.5-7.0 million ha of restorable rangeland in Ethiopia.

As discussed in Section 2.6, CEADIR assumed that each hectare of land under deferred-rotation grazing or active restoration would increase soil carbon storage by 1.72 tCO$_2$e/year for 20 years. CEADIR assumed no additional soil carbon storage from fodder cultivation because these areas typically had prior vegetative cover and were tilled for maize production. Table 12 shows the undiscounted benefits of increasing soil carbon storage from scaling up restoration of degraded rangeland nationwide over 50 years at the three values for the social cost of carbon. It does not account for the social costs of potentially higher methane emissions from associated increases in livestock populations.

TABLE 11. Economic NPVs of Scaling Up the Pilots to 3.5 Million Hectares, Excluding GHG Impacts, at a 50 Year Time Horizon and a 12 Percent Discount Rate

Improved Practice	Economic NPV Per Household (U.S. Dollars)	Area Per Household (Hectares)	Economic NPV Per Hectare (U.S. Dollars)	Economic NPV For 3.5 Million Hectares (U.S. Dollars)
Deferred-rotation grazing	-$1,404	2.5	-$561.60	-$1,965,600,000
Active restoration of degraded rangeland	$2,937	0.5	$5,873	$20,557,140,081
Fodder cultivation	$2,121	1.74	$1,219	$4,266,024,554

TABLE 12. Undiscounted Benefits of Increased Soil Carbon Storage from Scaling Up Restoration of Degraded Rangeland Over 50 Years at Three Values for the Social Cost of Carbon

Social Cost of Carbon (U.S. Dollars/tCO_2e)	Low Restoration (Million Hectares)	High Restoration (Million Hectares)	Low Peak Annual Value (U.S. Dollars)	High Peak Annual Value (U.S. Dollars)	Low Cumulative Value (U.S. Dollars)	High Cumulative Value (U.S. Dollars)
$8.00	3.5	7.0	$48,000,000	$97,000,000	$965,000,000	$1,930,000,000
$15.00	3.5	7.0	$90,000,000	$181,000,000	$1,810,000,000	$3,619,000,000
$25.00	3.5	7.0	$151,000,000	$302,000,000	$3,016,000,000	$6,032,000,000

Section 2.6 also noted that any increase in ruminant livestock populations associated with adoption of improved production practices would increase enteric emissions of methane. Table 13 contains methane emission factors for four types of ruminant livestock and the annual social cost of these emissions at the three values of the social cost of carbon. The participants in the pilot tests in the Oromia lowlands increased their livestock herds after adopting improved production practices. However, it is uncertain whether adoption of the improved practices at a national scale would increase the total number of ruminant livestock in the country by the same proportions. Farmers in some parts of the country may be less interested in expanding their livestock herds due to less favorable growing conditions in typical years, higher risks of severe droughts, or transportation or marketing constraints.

TABLE 13. Methane Emissions Per Animal By Type of Livestock and the Annual Cost of Methane Emissions Per Animal at Three Values of the Social Cost of Carbon

Type of Livestock	Annual Methane Emissions Per Animal (tCO_2e)	Annual Cost of Methane Emissions Per Animal (U.S. Dollars)		
		Social Cost of Carbon: $8/$tCO_2e$	Social Cost of Carbon: $15/$tCO_2e$	Social Cost of Carbon: $25/$tCO_2e$
Cattle	0.868	$6.94	$13.02	$21.70
Goats	0.140	$1.12	$2.10	$3.50
Sheep	0.140	$1.12	$2.10	$3.50
Camels	1.288	$10.30	$19.32	$32.20

Table 14 presents the social cost of increased methane emissions from potential increases in livestock populations when the improved practices are scaled up to 3.5 million hectares. This table was based on the assumption that the national increases in livestock populations would be proportional to the increases in livestock populations in the Oromia lowlands pilot tests. Since this assumption might not be valid, as discussed above, the actual methane emission increases at the national scale could be lower than those presented in this table.

TABLE 14. Annual Social Cost of the Methane Emissions from 3.5 Million Hectares of the Improved Practices at Three Values of the Social Cost of Carbon (U.S. Dollars)

Improved Practice	Annual Methane Emissions Per Household (tCO_2e)	Land Area Per Household (Hectares)	Annual Methane Emissions Per Hectare (tCO_2e)	Annual Social Cost of Methane Emissions (U.S. Dollars)		
				Social Cost of Carbon: $8/$tCO_2e$	Social Cost of Carbon: $15/$tCO_2e$	Social Cost of Carbon: $25/$tCO_2e$
Deferred-rotation grazing	-2.181	2.5	-0.872	-$24,429,440	-$45,805,200	-$76,342,000
Active restoration of degraded rangeland	-2.198	0.5	-4.396	-$123,088,000	-$230,790,000	-$384,650,000
Fodder cultivation	-0.854	1.74	-0.491	-$13,742,529	-$25,767,241	-$42,945,402

Since the increase in the livestock population was relatively small for deferred-rotation grazing, the increased soil carbon sequestration exceeded the carbon dioxide equivalent of the increased methane emissions. As a result, deferred-rotation grazing was the only one of the three improved practices with positive economic benefits from a net reduction in GHG emissions. However, the global social value of the net reduction in GHG emissions from deferred-rotation grazing was small and unlikely to be realized because the financial NPV of this production practice was unfavorable. Conversely, the global social cost of the net increase in GHG emissions from active restoration of degraded pasture land was small relative to the economic gains from these two practices, which are more likely to be adopted.

4. CONCLUSIONS

Data Strengths and Limitations. In the three pilot tests in the Oromia lowlands, deferred-rotation grazing was implemented for four years, active restoration of degraded land for three years, and fodder cultivation for five years. These practices were not implemented long enough to generate sufficient cost and benefit data over their 15 to 20 year periods of effectiveness. The three pastoralist associations did not have written records on the pilot tests and no progress, monitoring, or evaluation reports were available from the participating NGOs.

As a result, this CBA had to rely on surveys of livestock farmers and focus group discussions with pastoralist association leaders for detailed data. Respondents were asked to recall information about a 10-year period—five years before and five years after adoption of improved production practices. Furthermore, the improved practices had been adopted four or five years earlier. It may have been difficult for the respondents to remember information from this period to respond to the questions accurately.

Due to budget and time constraints, the team was not able to verify reported inputs and yields with direct measurements. However, the focus group discussions provided a useful check on the survey results. Some respondents reported spending more time on the improved production practices than the amount reported by experts. Some respondents reported selling fewer livestock than local pastoralist association leaders reported. Some experts and pastoralist association leaders felt that households tended to understate their revenues and overstated their costs for cultural reasons or in hopes of receiving donor support (*instrumental* or *strategic bias*). As a result, the team used the lower time and higher livestock sales estimates in the CBA.

More accurate information could be obtained from timely monitoring and evaluation of other applications of improved livestock production practices in Ethiopia or elsewhere. It would also be useful to have more reliable data on how input costs and farm product prices vary in normal rainfall, moderate drought, and severe drought years.

Temporal and Spatial Distribution of Benefits and Costs. The three improved practices considered in this study required relatively large up-front investments compared to their annual returns. At low discount rates, the financial and economic NPVs were positive for all three improved practices. However, the incremental NPV for deferred-rotation grazing was negative at a 12 percent real discount rate. The main reason for the negative NPV of deferred-rotation grazing at the higher discount rate was the cost of purchasing fodder during the time while the grazing land rested. If a cheaper way to sustain herds could be found, deferred-rotation grazing could have a positive NPV at the 12 percent discount rate. Active restoration of degraded pasture land and fodder cultivation had large positive NPVs at that discount rate.

The data for each of these improved practices derived from single pilot tests in one location. The results could differ for pilot tests at other locations and times. Nevertheless, the findings from this CBA can be useful in designing other small pilots or larger applications of these practices. This CBA also shows the importance of collecting and maintaining location-specific information on development experiences.

Need for Financing. Although the financial NPVs were favorable, the payback periods were six years for active restoration of degraded rangeland and four years for fodder cultivation. These payback periods are too long for individual low-income farmers or even their associations. The pilot tests did not provide long-term loans to cover the initial capital costs and bridge the gap before improved practices became profitable. The lack of loan financing may explain why the improved practices promoted in these pilot tests did not continue to be implemented. Long-term financing is critical for individual farmers or associations interested in adopting improved production practices.

Some interviewees who had not participated in these pilot tests noted that they would need financing to adopt these practices. Small-scale livestock farmers in the study area generally lack access to long-term loans. Farmers in the area can obtain short-term loans for annual crop production that only cover the few months between planting and harvesting. The high transaction costs and risks of providing individual loans to low-income farmers can be reduced by providing loans to farmer groups or associations. Widespread adoption of the improved production practices may also require identifying or adapting improved production alternatives with lower costs and larger and faster benefits.

Need to Understand Livestock Farmer Decision Making and Markets. Cost-benefit analysis assumes that livestock farmers make rational financial decisions to maximize profits. However, small-scale livestock farmers in Ethiopia have traditionally viewed livestock as a store of wealth and have not necessarily maximized the financial value of their production. Consequently, a CBA for livestock production in this study area should be interpreted with caution.

Prior to the pilot tests, the participating livestock farmers often moved their livestock to different grazing areas, rather than purchasing fodder. The participating livestock farmers increased their hay purchases during the pilot tests and continued to do so after the pilots ended. Most of the surveyed livestock farmers now recognize the necessity of improving pasture management because the quantity and quality of available pasture land in the areas have decreased and are expected to continue to deteriorate. In the future, most livestock farmers in developing countries will need to adopt more intensive l production practices.

Some of the participating livestock farmers did not regularly sell live animals or slaughter them for meat for sale or household consumption. Many only sold live animals or when a special financial need arose. Some did not even harvest the milk from their livestock. However, cultural attitudes toward livestock as a store of wealth rather than a business activity may change over time with modernization. Livestock farmers with more education or training may make decisions on a more commercial basis.

Further research is needed to understand the knowledge, attitudes, markets, and constraints faced by livestock farmers in different parts of Ethiopia. Barriers to adoption of financially preferable opportunities include insufficient awareness of production alternatives and their financial benefits and costs, limited access to extension services to implement improved practices, uncertainty about land tenure or use rights, and sociocultural issues (Pegels *et al*. 2015).

Different Characteristics and Needs of Agropastoralists and Pastoralists. This CBA focused on agropastoralists that are involved in crop and livestock farming. Agropastoralists have access to land in settled farm locations and also practice extensive livestock grazing. Although there is potential to increase their incomes and resilience, agropastoralists in Ethiopia have received relatively little assistance to help them adopt better technologies.

Ethiopia also has 12 million pastoralists (nomadic herders) including those transitioning from pastoralism (ENA 2019). Pastoralists lack land for settled crop production and generally operate in fragile or difficult environments and have lower incomes, less education, and fewer resources to cope with climate and weather risks. Abdulahi (2019) reported that pastoralists used 61 percent of the land area of Ethiopia. About 97 percent of the pastoralists were in lowland areas of Afar, Somali, Oromiya, and the Southern Nations, Nationalities, and Peoples Region (SNNPR), but they often cross national borders. Abdulahi (2019) noted that many previous efforts to settle pastoralists have failed. In some areas, competition for land has led to conflicts between pastoralists and agropastoralists.

Pastoralists are an important target group for development assistance to alleviate poverty and malnutrition, but require different types of support than agropastoralists. USAID-funded a five-year Pastoralist Areas Resilience Improvement and Market Expansion (PRIME) Activity that began in October

2012 and focused on vulnerable populations in the arid lands of Ethiopia. Smith *et al.* (2019) evaluated the impacts of the PRIME Activity.

The Government of Ethiopia is finalizing a pastoral development policy and strategy (Ethiopia News Agency 2019). The draft policy recommends comprehensive land use planning to guide support for agropastoralists, pastoralists, and off-farm livelihoods on a more complementary basis.

Risks, Uncertainty and the Need to Increase Efficiency. Livestock and crop production are susceptible to many risks, including weather and climate, pests and diseases, and changes in input costs and product prices. Uncertainty is high because the probabilities of these risks are difficult to predict. Low-income farmers and pastoralists already face large losses during severe droughts and cannot afford to take on more risk. Severe droughts that sharply reduce livestock populations can bring years of income losses, food insecurity, and negative human health and social outcomes. This study addressed risks and uncertainty by using sensitivity analysis to examine the effects of severe droughts and multiple discount rates and values for the social cost of carbon.

Most of the arid and semi-arid grazing land in Ethiopia would benefit from conservation or restoration. However, there are barriers to implementing these activities, such as insufficient access to financing, land and resource use rights, political or social conflicts, extension capacity services, and the need to scale up production and sale of hay to feed livestock during rangeland restoration. Even in normal rainfall years, rangelands in Ethiopia are already resource degradation and there is insufficient fodder cultivation for efficient production of livestock products. An increase in ruminant livestock populations could result in more unproductive animals unless more animal feed is produced in country or imported.

Climate Change and Drought Resilience. An increase in the frequency or severity of droughts would reduce crop and livestock productivity under the baseline and improved production cases. Even if livestock farmers become more financially resilient by adopting more profitable practices, they are likely to experience substantial income and asset losses from the severe droughts that occur in Ethiopia.

Economic Benefits from Reducing Environmental Externalities. Economic benefits from reducing negative impacts on other users of land and water resources and mitigating climate change can justify subsidies to help low-income livestock farmers improve their production practices. However, subsidies can be counterproductive if they increase livestock populations beyond the long-term, carrying capacity of the natural resource base and increase ruminant emissions of methane.

Potential Gains from Shifting from Ruminants to Poultry. The efficiency of animal protein production could increase if dietary patterns can be changed to shift some ruminant meat consumption to poultry meat and eggs. This dietary shift could reduce total GHG emissions from livestock if ruminant populations are allowed to decrease, but it can be difficult to change food preferences in developing countries. Furthermore, the desired GHG emission reductions will not occur if farmers continue to hold ruminant livestock as a store of wealth. Public and private sector efforts to improve poultry production can also be important in increasing the income of rural women.

REFERENCES

aan den Toorn, Stephen; Machteld van den Broek; and Ernst Worrell. 2017. "Decarbonizing Meat: Exploring Greenhouse Gas Emissions in the Meat Sector." *Energy Procedia* 123, (September): 353-360. https://www.sciencedirect.com/science/article/pii/S1876610217328424#!.

Abdulahi, Abduselam. 2019. "Pastoralism and Development Policy in Ethiopia: A Review Study." *Budapest International Research and Critics Institute (BIRCI) Journal: Humanities and Social Sciences*. 2 (01-11). 10.33258/birci.v2i4.562.

Adem, Anwar; Wolde Mekuria; Charles Nicholson; Tammo Steenhuis; and Seifu Tilahun. 2016. *Enhancing Ecosystem Services in the Upper Blue Nile Basin, Ethiopia Through Soil and Water Conservation Implementation*. Report presented at the First African ESP Conference in Nairobi, November 21-25, 2016. https://cgspace.cgiar.org/handle/10568/82756.

Beattie, Bruce; C. Robert Taylor; and Myles Watts. 2009. *The Economics of Production*. *Second Edition*. Malabar: Krieger Publishing.

Central Statistical Agency. 2012. *Livestock Sample Survey 2011-12 (2004 E.C.)*. Addis Ababa: Central Statistical Agency, Ministry of Finance and Economic Development. http://catalog.ihsn.org/index.php/catalog/3400.

Central Statistical Agency. 2017. *CSA: Agricultural Sample Survey, 2016/17 (2009 E.C.), Volume II: Report on Livestock and Livestock Characteristics (Private peasant holdings)*. *Statistical Bulletin 585*. Addis Ababa: Central Statistical Agency, Federal Democratic Republic of Ethiopia.

Christopoulos, Dimitrios. 2009. *Peer Esteem Snowballing : A Methodology for Expert Surveys*. Paper presented at the Eurostat Conference for New Techniques and Technologies for Statistics, 2009.

Conant, Richard; Carlos Cerri; Brooke Osborne; and Keith Paustian. 2017. "Grassland Management Impacts on Soil Carbon Stocks: A New Synthesis." *Ecological Applications* 27, no. 2 (March): 662–68. https://esajournals.onlinelibrary.wiley.com/doi/full/10.1002/eap.1473.

Crewett, Wibke; Ayalneh Bogale; and Benedikt Korf. 2008. *Land Tenure in Ethiopia: Continuity and Change, Shifting Rulers, and the Quest for State Control*. Washington, DC: CGIAR Systemwide Program on Collective Action and Property Rights.

Daigneault, Adam; Philip Brown; and David Gawith. 2016. "Dredging Versus Hedging: Comparing Hard Infrastructure to Ecosystem-Based Adaptation to Flooding." *Ecological Economics* 122 (February): 25–35. https://www.sciencedirect.com/science/article/pii/S092180091500467X?via%3Dihub.

Deininger, Klaus; Tekie Alemu; and Daniel Ayalew Ali. 2011. "Impacts of Land Certification on Tenure Security, Investment, and Land Market Participation: Evidence from Ethiopia." *Land Economics* 87, no. 2 (May): 312-334. http://le.uwpress.org/content/87/2/312.

Dandesa, Tilahun; Diriba Korecha; Nigatu Lisanu; and Bedassa Regassa Cheneka. 2017. "Assessment of Climatic Variability and Development of Localized Climate Prediction Method for Livestock Production in Borana Area, Southern Ethiopia. *Environmental Science: An Indian Journal* 13, no. 3 (May): 137-196. https://www.researchgate.net/publication/320869028_Assessment_of_Climatic_Variability_and_Development_of_Localized_Climate_Prediction_Method_for_Livestock_Production_in_Borana_Area_Southern_Ethiopia.

Desta, Solomon; and D. Layne Coppock. 2002. "Cattle Population Dynamics in the Southern Ethiopian Rangelands, 1980-97." *Journal of Range Management* 55: 439-451. https://journals.uair.arizona.edu/index.php/jrm/article/view/9740/9352

Ericksen, Polly and Todd Crane. 2018. *The Feasibility of Low Emissions Development Interventions for the East African Livestock Sector: Lessons from Kenya and Ethiopia*. Research Report 46. Nairobi: International Livestock Research Institute (ILRI). https://ccafs.cgiar.org/publications/feasibility-low-emissions-development-interventions-east-african-livestock-sector#.XdL_9PkzaUk.

ENA. 2019. "Ethiopia to Introduce Pastoralist Dev't Strategy, Policy." Addis Ababa: Ethiopia News Agency. https://www.ena.et/en/?p=6781

Hagos, Fitsum and Stein Holden. 2006. "Tenure Security, Resource Poverty, Public Programs, and Household Plot-Level Conservation Investments in the Highlands of Northern Ethiopia." *Agricultural Economics* 34, no. 2 (March): 183–196. https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1574-0864.2006.00117.x.

Herrero, Mario; Dorapo Enahoro; Delia Grace; Nancy Johnson; Jemimah Njuki; Mariana Rufino; and Sylvia Silvestri. 2013. "The Roles of Livestock in Developing Countries." *Animal* 7, no. s1 (September): 3–18. https://www.cambridge.org/core/journals/animal/article/roles-of-livestock-in-developing-countries/F349D13CBF84599AF44952632BC2E48C.

Hussen, Nizam; Aynalem Haile; K. Hikuepi; S. Kumsa; and G. Legese. 2013. *Analysis of Goat Value Chains in Yabello District, Borana Zone, Ethiopia*. Addis Ababa: International Center for Agricultural Research in the Dry Areas. Nairobi: International Livestock Research Institute (ILRI). https://cgspace.cgiar.org/handle/10568/35370.

IPCC (Intergovernmental Panel on Climate Change). 2006. *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Kanagawa: National Greenhouse Gas Inventories Programme. https://www.ipcc-nggip.iges.or.jp/public/2006gl/.

———. 2014. *Climate Change 2014: Synthesis Report*. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Core Writing Team, Leo Meyer, and Rajendra Pachauri, eds. Geneva: Intergovernmental Panel on Climate Change. https://www.ipcc.ch/site/assets/uploads/2018/05/SYR_AR5_FINAL_full_wcover.pdf.

Kashangaki, John, and Polly Ericksen. 2018. *Cost–benefit Analysis of Fodder Production as a Low Emissions Development Strategy for the Kenyan Dairy Sector*. Nairobi: International Livestock Research Institute (ILRI). https://cgspace.cgiar.org/bitstream/handle/10568/97426/LED%20investment%20plan%20final.pdf.

Kimball, Tom. 2011. "Livestock Production Systems and Their Environmental Implications in Ethiopia." In *Economic Policy Review: Key Issues in Ethiopia 2011*. Waterville: Colby College Environmental Studies Program. http://web.colby.edu/eastafricaupdate/files/2012/02/Environmental-Policy-Review-2011_Chapter-3_color_small.pdf.

McPeak, John; Heather Huntington; and Peter Little. 2014. *USAID/Ethiopia Land Administration to Nurture Development (LAND): Impact Evaluation Design Report*. Washington, DC: Cloudburst Consulting Group, Inc. Prepared for the U.S. Agency for International Development. https://land-links.org/wp-content/uploads/2017/09/LAND-Oromia_Design-Report_2014-08.pdf

Mekuria, Wolde; Kindeya Gebrehiwot; Mitiku Haile; Bart Muys; Jan Nyssen; and Edzo Veldkampl. 2007. "Effectiveness of Exclosures to Restore Degraded Soils as a Result of Overgrazing in Tigray, Ethiopia." *Journal of Arid Environments* 69, no. 2 (April): 270–84. https://www.sciencedirect.com/science/article/pii/S0140196306003491?via%3Dihub.

Mekuria, Wolde; Tadele Amare; Tesfaye Feyisa; Menale Wondie; Asmare Wubet; and Birru Yitaferu. 2018. "Restoration of Degraded Landscapes for Ecosystem Services in North-Western Ethiopia." *Heliyon* 4, no. 8 (August): e00764.

Mengistu, Dirriba and Tamiru Amanu. 2016. "Assessments of Cereals Marketing Systems in Borena Zone, Southern Ethiopia." *Journal of Marketing and Consumer Research* 22 (April): 98-102. https://www.researchgate.net/publication/324259549.

Ng'ang'a, Stanley; Vincent Ansah; George Essegbey; Evan Girvetz; Naaminong Karbo; Sam Kingsley; Vail Miller; and Delali Nautsukpo. 2017. "Cost and Benefit Analysis for Climate-Smart Agricultural (CSA) Practices in the Coastal Savannah Agro-Ecological Zone (AEZ) of Ghana." Cali, Colombia: International Center for Tropical Agriculture CIAT, Prepared for USAID/Ghana. https://cgspace.cgiar.org/handle/10568/83464

Ng'ang'a, Stanley; Evan Girvetz; Caroline Mwongera; Chris Mwungu; and An Notenbaert. 2017. "Cost and Benefit Analysis for Climate-Smart Soil Practices in Western Kenya." Kampala: International Center for Tropical Agriculture, CIAT Publication 439. https://cgspace.cgiar.org/handle/10568/82618.

Ng'ang'a, Stanley; Ken Giller; Mariana Rufino; and Mark Van Wijk. 2016. "Adaptation of Agriculture to Climate Change in Semi-Arid Borena, Ethiopia." *Regional Environmental Change* 16, no. 8 (December): 2317–30. https://link.springer.com/article/10.1007%2Fs10113-016-0940-4.

Pegels, Anna; Aurelia Figueroa; and Babette Never. 2015. *The Human Factor in Energy Efficiency: Lessons from Developing Countries*. Bonn: Deutsches Institut für Entwicklungspolitik gGmbH (German Development Agency, GiZ). https://www.die-gdi.de/uploads/media/The_Human_Factor_in_Energy_Efficiency_FINAL_LOW_RES.pdf.

Project Concern International. 2014. *Reaching Pastoralists Through Geo-Satellite Information for Improved Decision-making: Project Completion Final Report.* San Diego: Project Concern International.

Rettberg, Simone; Gabriele Beckmann; Margitta Minah; and Anja Schelchen. 2017. *Ethiopia's Arid and Semi-Arid Lowlands: Towards Inclusive and Sustainable Rural Transformation*. Berlin: Centre for Rural Development (SLE). https://edoc.hu-berlin.de/bitstream/handle/18452/18671/03.pdf?sequence=1.

Robinson-Pant, Anna. 2018. *Learning Knowledge and Skills for Agriculture to Improve Rural Livelihoods.* Rome: United Nations Educational, Scientific and Cultural Organization. https://unesdoc.unesco.org/ark:/48223/pf0000245765.

Schwartz, Horst Juergen; Salim Shaabani; and Dierk Walther. 1991. Range Management Handbook of Kenya: Marsabit District. Nairobi: Republic of Kenya Ministry of Livestock Development. https://www.researchgate.net/publication/260086759_Range_Management_Handbook_of_Kenya_Marsabit_District.

Shapiro, Barry; Gezahegn Aboset; Solomon Desta; Getachew Gebru; Henok Mechale; Asfaw Negassa; and Kidus Nigussie. 2017. *Ethiopia Livestock Sector Analysis*. Nairobi: Ethiopia Ministry of Livestock and Fisheries and the International Livestock Research Institute (ILRI). https://cgspace.cgiar.org/bitstream/handle/10568/92057/LSA_Ethiopia.pdf?sequence=3&isAllowed=y.

Smith, Lisa; Karen Fox; Tim Frankenberger; Tiffany Griffin; and Suzanne Nelson. 2019. *Ethiopia Pastoralist Areas Resilience Improvement and Market Expansion (PRIME) Project Impact Evaluation: Endline Survey Report*. Washington, DC: Resilience Evaluation, Analysis and Learning (REAL) Associate Award. https://www.fsnnetwork.org/sites/default/files/Ethiopia%20PRIME%20Endline%20Report_FINAL_OCT_2019_508.pdf.

Stickler, Mercedes and Heather Huntington. 2005. "Perceptions of Tenure Security: An Exploratory Analysis of Pretreatment Data in Rural Communities across Ethiopia, Guinea, Liberia, and Zambia." Report presented at the Annual World Bank Conference on Land and Poverty in Washington, DC, March 23-27, 2005. https://www.land-links.org/wp-content/uploads/2016/09/Perceptions_of_Tenure_Security-Ethiopia_Guinea_Liberia_Zambia.pdf.

Suryabhagavan, Karuturi Venkata. 2017. “GIS-based climate variability and drought characterization in Ethiopia over three decades." *Weather and Climate Extremes* 15 (March): 11-23. https://www.sciencedirect.com/science/article/pii/S2212094716300366?via%3Dihub.

Teshome, Asaminew and Jie Zhang. 2019. “Increase of Extreme Drought over Ethiopia under Climate Warming.” *Advances in Meteorology* 2019, no. 5235429. https://www.hindawi.com/journals/amete/2019/5235429/cta/.

Tilahun, Abera; Dana Hoag; and Beyene Teklu. 2017. “Challenges and Contributions of Crop Production in Agro-Pastoral Systems of Borana Plateau, Ethiopia.” *Pastoralism* 7, no. 2 (February). https://pastoralismjournal.springeropen.com/articles/10.1186/s13570-016-0074-9#citeas.

Traore, Bouba; Marc Corbeels; Ken Giller; Mariana Rufino; and Mark van Wijk. 2013. “Effects of Climate Variability and Climate Change on Crop Production in Southern Mali.” *European Journal of Agronomy* 49 (August): 115–125. https://www.sciencedirect.com/science/article/pii/S1161030113000518?via%3Dihub.

U.S EPA. 2017. “Understanding Global Warming Potentials.” U.S. Environmental Protection Agency. https://www.epa.gov/ghgemissions/understanding-global-warming-potentials.

USAID. 2015. USAID Guidelines: Cost-Benefit Analysis (CBA). Washington. DC: U.S. Agency for International Development.

Viste, Ellen; Diriba Korecha; and Asgeir Soreberg. 2013. "Recent Drought and Precipitation Tendencies in Ethiopia." *Theoretical and Applied Climatology* 112, no. 3-4 (May): 535-551. https://link.springer.com/article/10.1007/s00704-012-0746-3.

Vétérinaires sans Frontières International. 2018. “From Emergency to Development: Building Resilience through Livestock-Based Interventions.” *VSF International Policy Paper* 4. http://vsf-international.org/wp-content/uploads/2018/02/Policy_Paper_4-livestock-emergency-web.pdf.

Wood, Peter John. 2010. “Climate Change and Game Theory.” *Environmental Economics Research Hub Research Reports* 62. https://ageconsearch.umn.edu/record/95061.

World Bank. 2019. “Climate Change Knowledge Portal.” World Bank. Accessed November 22, 2019. https://climateknowledgeportal.worldbank.org/country/ethiopia/climate-data-historical

Worldometers. 2019. “Population of Ethiopia (2019 and Historical).” Worldometers. Data from November 16, 2019. http://www.worldometers.info/world-population/ethiopia-population/.